LECTURES

ON

ILLUMINATING ENGINEERING

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XI

THE PHYSIOLOGICAL ASPECTS OF ILLUMINATING ENGINEERING

By Percy W. Cobb

CONTENTS

Lecture I

Physiological Optics.

LECTURE II

Special Applications

a. Photometry. Difficulty in case of color difference.
   Methods of heterochromatic photometry.
      1. Direct comparison. Difficulty.
      2. Method by visual acuity. Subject to equal difficulty with above. Inherent roughness of the method.
      3. Flicker photometry. Objections to all methods are variations in luminous values of colors:
         1. At varying intensities.
         2. For different eyes.
         3. In different parts of visual field of the same eye.

b. Glare.
   Provisional definition " Light out of place." Reaction of eye to misplaced light (1) by pain, (2) by difficult vision.
   Pain from light often relative to state of eye. Dark adaptation. Occupation-photophobia. In diseases of the eye.
   Embarrassed vision. Any circumstance within or without the eye which interferes with vision calls for increased work of eye-muscles.
   Conditions in illumination which interfere with vision.
   Light source in field.
      1. Tendency of eye to wander to it.
      2. Relative invisibility of other objects. Induction.
   Induction. Either a detriment or advantage to vision according to circumstances.
   Scattered light and secondary images in the eye. " Halos "—why not always seen.
   Wide range of eye for full adaptation. Example of room lit at various intensities. Range at any one instant. Black : white = 1 : 20.
   Probable range in ordinary illuminations. Scattered light always of a much lower order of intensity. Not in evidence unless coming from source of relatively very high intensity.

c. Injuries from radiation.
   Difficulty of determining exact wave lengths responsible. Review of injuries caused by radiation. In the more exposed part of the eye. In the retina. In the lens. Transmission of the eye-media for infra-red. For ultra-violet.
   Bearing of this on location of injuries. Infra-red ruled out as cause of disturbance. Ultra-violet is the disturbing factor in superficial " burns."
   Practical application. Question is not only " What wave lengths? " but " What intensity? " Comparison of sources with daylight as to distribution. Cause of discomfort with artificial light. Fatigue and wrong system of illumination.

Lecture I

Physiological Optics

The eye is an optical instrument. In more definite terms, it is to be considered optically as not different from a photographic camera—having a lens of its own, an iris where the camera has a diaphragm, a sensitive retina corresponding to the sensitive plate. Further, the means of adapting the eye to objects at different distances is not wanting—the function of accommodation changing the shape of the lens of the eye (not the distance of the retina) to bring objects at different distances into focus.

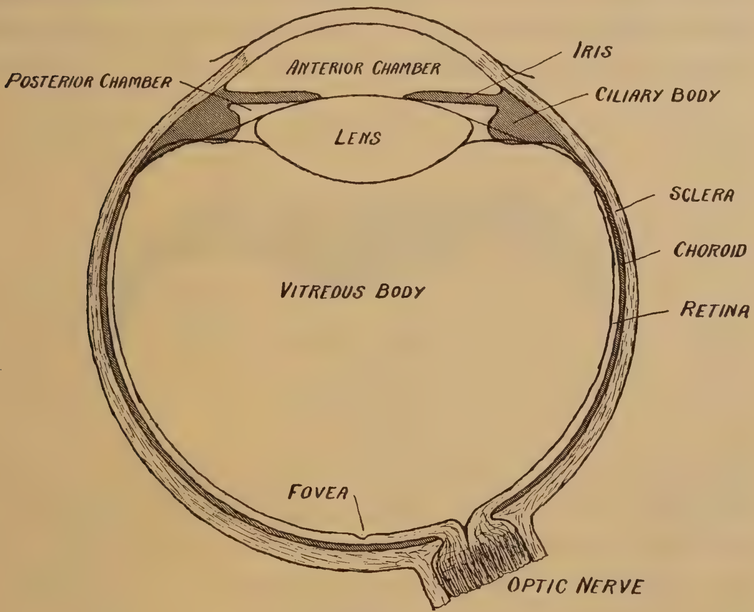


Fig. 1.

The eyeball is in shape nearly spherical. Its walls are composed of three layers, an outer, fibrous coat, called the sclera, which gives the eyeball its strength, and of which the portion that is visible is known as the white of the eye. Next within this is the choroid coat, composed chiefly of blood vessels whose function is to nourish the sclera, and more particularly the retina, which forms the third, inmost layer of the wall of the eyeball, and is the sensitive layer on which the impressions of light are received and from which corresponding nervous impulses are transmitted to the brain.

The eyeball is in shape nearly spherical and, as we said, the outer coat is white. At the forward pole, however, this coat has a different structure and becomes perfectly transparent, forming a more convex surface than the rest of the eyeball. This part of the eye is called the cornea, and its surface is the point of entry of light into the eye and forms the first refracting surface of its dioptric system. Back of the cornea is a space filled with a clear, watery substance called the aqueous or aqueous humor, this space being divided by the iris into what are called, respectively, the anterior and posterior chambers. The iris is a prolongation forward and inward of the middle or choroid coat of the eye, and forms a ring-shaped curtain, supported at its outer edge and composed partly of muscular tissue, by virtue of which it is capable of changing

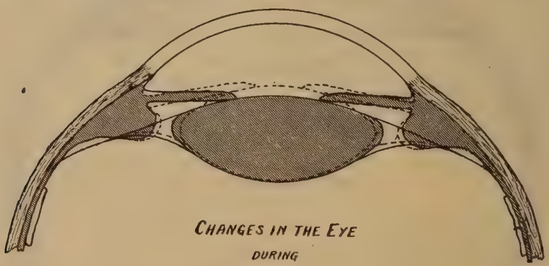


FIG. 2.

the diameter of its central opening, the pupil of the eye. By this mechanism the brightness of the image falling on the retina is controlled, and, further, the sharpness of the image is increased by contraction of the pupillary orifice owing to the general decrease in the diameter of the cone of light rays corresponding to any given point of object and image.

The inner edge of the iris rests against the lens, or more properly, the lens capsule. The lens is a transparent elastic body, confined between two layers of thin membrane known as the lens capsule. These two layers pass outward so that their edges meet and are inserted into a muscular ring known as the ciliary body or muscle, corresponding about to the outer edge of the iris. It is evident that the lens must change in shape when the tension on these two layers of the capsule changes, and accommodation is brought about in this way, so that the eye forms a clear image of

a near or far object as necessity dictates. There are two theories as to the exact mechanism of this process. We do not need to discuss these further than to state one point on which they agree, namely, that in a normal eye the ciliary muscle is at rest when a distant object is in focus. Eye-strain, of which you all know something, depends in part, at least, on strain of the ciliary muscle, and a practical corollary we can deduce here is that tired eyes are rested by looking at objects some distance away—say 15 feet or over—provided these objects are neither very dark nor very bright, and are not moving.

Back of the lens and the lens capsule the eyeball is filled with a clear, jelly-like material, known as the vitreous, the vitreous body or, in the older nomenclature, as the vitreous humor.

It will be seen from this that the light rays, striking the front of the eye, pass through the cornea and the aqueous, passing through the pupillary opening of the iris, and then through the lens and vitreous, finally striking the retina.

We must pause here to consider the value of transparent structures as an optical system. What happens to the light rays in passing through them in the way we have just outlined? To begin with, the aqueous and vitreous have a refractive index, 1.3365, about equal to that of water. The cornea has a somewhat higher index of refraction, 1.377, but its two surfaces being so nearly parallel, the course of the light rays is scarcely altered in passing through it. The lens has a higher refractive index. It is, however, not uniform in this respect, the portions nearest its center having the greatest refractivity, the superficial portions the least. The mean value for the refractive index of the lens as a whole is given as 1.437.

Optically, then, there are three surfaces in the eye to be considered as refracting surfaces: (1) The anterior corneal surface, radius 7.8 mm., where, owing to the high difference between the refractive indices of air and of the eye media, the greatest amount of refraction in the eye takes place. (2) The anterior lens surface. This changes its shape, as we before stated, according as the eye is accommodated for far or near objects, varying from a radius of curvature of 10 mm. for far objects to 6 mm. for near ones. (3) The posterior lens surface also changing, but only very slightly, with accommodation from 6 to 5.5 mm. radius of curvature.

The location of these surfaces, with respect to the retina in the

unaccommodated eye, is represented by these dimensions: From the center of the corneal surface to the anterior lens surface, 3.6 mm.; thickness of the lens, 3.6 mm.; posterior lens surface to retina, 14.6 mm.

To simplify the comprehension of the refractive value of the eye, the idea of a reduced eye or schematic eye has been originated, composed of a single refracting surface bounding a homogeneous refractive medium. From this, computations as to size of image, diffusion, circle, etc., can be made. It is sufficient here to remember that the distance from the nodal point to the retina is 15.5 mm., that is, any dimension of the retinal image (X) can be known by this proportion:

$$X : 15.5 = \text{dimension of object} : \text{distance to object.}$$

Along with the consideration of the eye as an optical instrument, we must not neglect to take note of its defects as such. On the ground of mathematical accuracy the eye cannot escape criticism. It has all the defects known to optical systems. Although it is not to be assumed that the refracting surfaces of the eye are truly spherical, yet an error corresponding to spherical aberration does exist, that is, the light rays passing through the peripheral portions of the pupillary opening do not come to a focus at the same point as the central ones, with the result that vision may be more distinct when we look through a small diaphragm than without it, even though the diaphragm does decrease the apparent illumination of the object looked at. Further, the eye is not corrected for color, although it is sometimes erroneously assumed to be. It is true that ordinarily colored fringes are not seen, but they may be made visible by the simple experiment of passing the edge of a card across the pupil, and as closely as possible to it, and at the same time looking at a dark, narrow object on a bright background parallel to the edge of the card. The edge of the object toward the card will be seen to have a blue fringe, the further edge a reddish one. Further, by looking at an incandescent filament through a cobalt glass, which transmits blue and some red, but not the intermediate colors, we will be able, by properly accommodating the eye to see either a red or a blue filament, but only one of these can be seen distinctly at any one time, the other appearing as an indistinct halo. The difference of refractive power of the eye for red and blue has been found to be 2.25 diopters, equivalent to a lens of about 44 cm. focal length.

A third optical defect of the eye is astigmatism. It is present almost universally in very slight degrees, both regular, i. e., such as can be corrected by a cylindrical lens, and irregular, which is beyond artifical correction. Those high degrees of astigmatism, constituting relatively serious defects of vision, cannot be considered here, nor can the other classical errors of refraction, namely, myopia, hyperopia and presbyopia, except to state briefly that such exist. We must mention, however, one or two other things which are especially noteworthy from the standpoint of physical optics. The various refractive surfaces of the eye are by no means accurately centered about a common axis. It has been shown that the lens is somewhat out of line with respect to the corneal surface, and the fovea of the retina (that point which is concerned with direct vision, i. e., when we look *at* an object) is not in line with either. Further, it is to be stated that the field of the eye is small—remembering that here we mean the field of most distinct vision. It is to be remembered that the actual field of vision of one eye is very large. The eye without being moved is capable of seeing, with less distinctness, objects far removed from the point of direct vision, but only a very small part of the retina is specialized in such a way as to enable us to read print under ordinary conditions.

To recapitulate: The optical defects of the eye are spherical aberration, astigmatism, eccentricity of the optical elements, smallness of field of distinct vision. These have been dwelt on at some length, not because it is wished to urge the inferiority of the eye as an optical instrument, but to emphasize in this connection a principle which underlies life and goes far to distinguish living from non-living material. It has been said that man can make a better photographic camera than the eye is, but he cannot make a better eye. What is meant is that the eye is a living thing, and as such has the power of adaptation in many ways to the conditions which it has to meet. In special instances it meets the conditions by rapid adjustment, and it can meet an astonishingly wide range of conditions if time is allowed for full adaptation to take place.

These adjustments are brought about in several ways. We have already spoken of accommodation, by which the lens of the eye is adjusted for objects at different distances. The eye can pick out not only a certain object, but any line of that object, and accommodation can be adjusted instantly to get the best possible

vision of that line. In that way some of the defects of the eye can be overcome. In this connection we must mention also the quick adjustment of the pupillary diameter to the changes in the amount and distribution of light falling on the eye, by which sudden changes in illumination are compensated. The complete range of the eye in its adaptation to various degrees of illumination is, however, far wider than can be accounted for by the extreme changes in pupillary area, and further, these changes in sensitiveness of

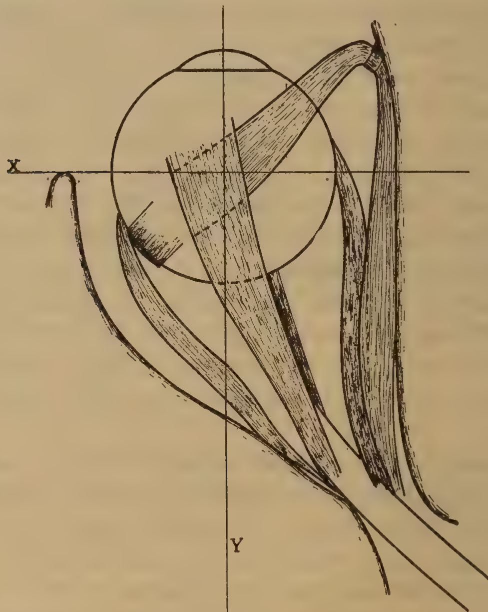


FIG. 3.—The Extrinsic Muscles of the Eye.

the eye do not become complete until half an hour or more has been spent under the new conditions, and must, for these reasons, be ascribed to distinct change in sensitiveness of the retina itself, a point to which we will recur later on.

A third means by which the eye makes good for its optical defects is the group of muscles by which the eyeball is turned in its socket. There are six of these for each eye, known as the extra-ocular muscles. In proportion to the size of these muscles the nerves entering them are much larger than the nerves supplying any other muscular structure of the body; and if we except the

heart, we can say that no other muscular structure is more incessantly active during waking hours than these muscles are. They are held in accurate balance with each other and with the state of accommodation of the eyes by nervous impulses from common nervous centers. When the eyes are accommodated for distance the visual axes of the two eyes are kept parallel to each other by these muscles, and remain parallel in whichever direction the eyes may be turned in their orbits. With every degree of accommodation for nearer objects there is a corresponding degree of turning in of the eyeballs with respect to each other, so that the visual axes always meet at the point looked at. Although the relation between these two movements, accommodation and its corresponding degree of convergence may be distorted to a limited extent, as by putting a prism of low deflecting power before one eye, and compelling a greater or less discrepancy between convergence and accommodation to compensate for it, yet such a disturbance can be of only limited extent, and if continued surely makes trouble.

The smallness of the field for distinct vision is well made up for by the action of these muscles. Any object in the outlying parts of the visual field that attracts the attention at once sets these muscles into action in such a way as to bring the image of that object on to the fovea, the most sensitive point of each retina, where its details become evident up to the maximum power of the eye.

Aside from the visible movements of the eyeballs, it is probable that much finer movements exist, not evident to ordinary inspection, which contribute in a high degree to the distinctness of vision of fine detail. A parallel to this is the behavior of touch sensation. If we simply rest the finger tips on a surface we do not get an accurate idea of the minute irregularities of the surface until we give the fingers a very slight movement. When we do this, the details of the surface are felt with surprising distinctness. It appears that by means of the fine movements of the eye the fovea is made to feel over the retinal image in an exactly similar way, and bring out its details. In support of this idea, it may be said that the retinal blood-vessels are so placed that when light enters the eye they always cast shadows in the light-sensitive layer, and yet these shadows are practically never seen by the eye in which they exist, since on movement of the eye the blood-vessels move in an exactly similar way, and there is no change of position of the shadows with respect to the retina. By a special mode of illumina-

tion the shadows can be shifted to a slightly different position and at once become visible.

(a) **Retinal Structure and Topography.** We cannot safely pass on to the question of retinal functions without first going over the known structure of the retina.

The retina or, as the ophthalmologist terms it, the "eye-ground," can be seen by means of the ophthalmoscope. This is essentially no more than a small perforated concave mirror by which light is

FIG. 4.—The Eye-ground.

thrown from a suitable source into the observed eye. The mirror is held close to the observed eye, and the observer looks through the opening in the mirror. The rays from the observed retina leave that eye as parallel rays, are received by the observer's eye as parallel, and brought to a focus on his retina as an image of the retina under observation.

Under these conditions the retina is seen as a reddish surface, crossed by numerous radiating blood-vessels (Fig. 4), which arise from an area of paler color than the rest, known as the optic disc. This is no more nor less than the end or "head" of the optic

nerve, as it enters the eye and before its fibers spread out and become a part of the retina. The nerve head and a variable portion of the retina about it form the well-known "blind spot" of the retina. These blood-vessels, it must be remembered, like the fibers of this nerve, spread out over the surface of the retina nearest to us, while the light-receiving organs are on the opposite side of the retina in such a way that the light to which ordinary vision is due has to pass through practically the whole thickness of the retina before reaching the sensitive organs. The shadows of these blood-vessels are always present on the sensitive layer under the conditions of ordinary vision.

The point of most distinct vision is a short distance away from the nerve head toward the temple. It is recognized by an indefinite, slightly darker spot on the retina, with a light center. At this point the blood-vessels are not visible, but they can be seen to approach it from all sides, dwindling in size down to invisibility, and so leaving the fovea and a small surrounding area free from the shadows of the vessels.

The microscope has shown the retina to be of most complicated structure. Indeed it is considered by anatomists, in view of its relations, to be chiefly a part of the brain pushed out in the course of development to meet the end organs.

The unit of which the nervous system is built up is known as a neuron. Briefly, this is a nerve cell plus its processes, of which the longest, in the most typical cases several feet long, is called the axis-cylinder process, and is the fiber of which nerves are built up, and which transmits the nervous impulse. The optic nerve is, as we shall see, a bundle of such fibers, leading from certain cells in the retina.

There are three sets of neurons concerned in the transmission of the impulse before it leaves the retina. The rods and cones, recognized as the seat of light reception, are the terminal portions of the outer set (II, Fig. 5B). The base of each rod or cone is continuous with a fiber which has on its course the nucleus of this neuron and at its other end comes into relation with the end of a similar fiber from the second set of neurons (at IV). These neurons, in a similar way, communicate with the third set, the "ganglion" cells (IX), from which the axis-cylinder processes (X) arise that collectively form the optic nerve. To consider what

further course the nervous impulses pursue, after reaching the brain, would detain us too long.

In addition to these three sets of cells described, there are wholly within the retina certain other cells which appear to have the function of associating different parts of the retina, called association and amacrine cells, variously formed, the association cells (4) with horizontally running processes of varying length, the amacrine cells (1) with many-branched processes forming a veritable tree in

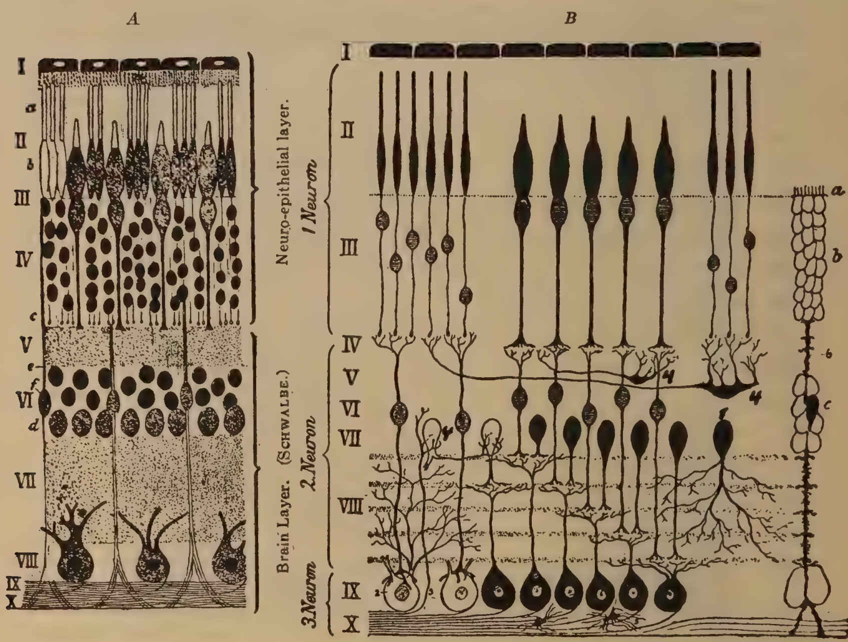


FIG. 5.—Scheme of the Structure of the Human Retina (after Souter in Posey and Spiller).

certain layers of the retina. We have then good reason to conclude that the impulse set up in any particular rod or cone is not to be considered as running an isolated course, even as far as the optic nerve. No more can we conclude that the impulses from the rods and those from the cones as two distinct classes are capable of independent consideration. Microscopic investigation of the connections of these nervous elements of the retina speak against it, and experimental investigation of retinal functions abundantly shows that every point of the retina is very much dependent in its

response to stimulation on the coexisting state of excitation of other parts of the retina, more especially, as may be supposed, parts near or adjacent to it.

No part of the retina is free from cones. The fovea itself, for an area of about 0.5 mm. in diameter, is supplied with cones only (I, Fig. 6). Outside this, the rods begin to appear (II). They become more and more frequent further from the center. The

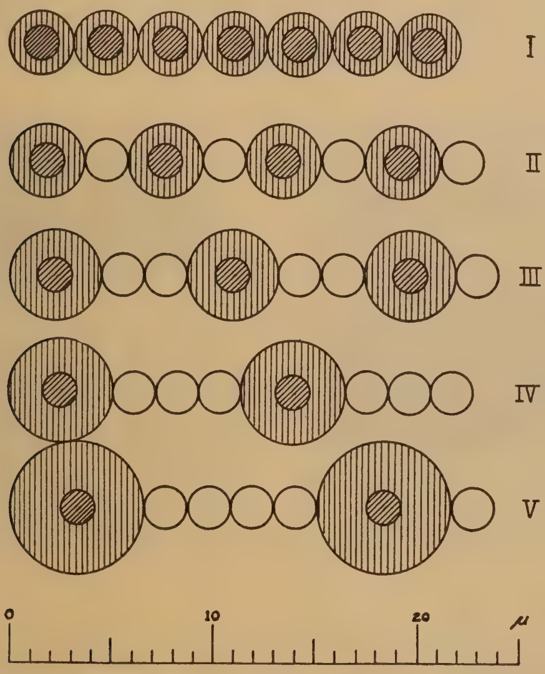
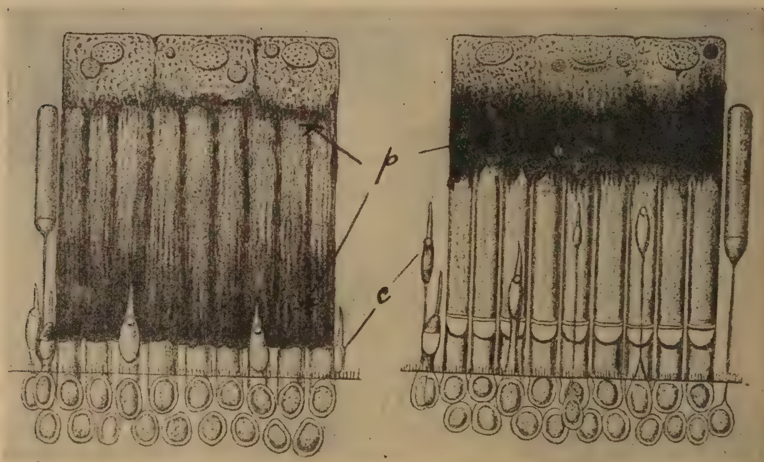


Fig. 6.—Relative Size and Distribution of Rods and Cones (after Zoth in Nagels' *Handbuch der Physiologie*).

cones at the same time become less and less frequent and larger in size (III, IV, V), persisting, however, to the very outer limit of the sensitive retina.

There are certain visible changes which have been shown to take place in the retina on exposure to light. There is a certain layer of cells just outside the layer of rods and cones containing abundant dark pigment. On exposure of the retina to light these cells apparently send down processes between the rods, much of the pigment going along with them so as to tend to optically isolate the

rods from each other (Fig. 7). At the same time the cones escape this in a measure by moving in the same direction toward the light. Another change which clearly takes place by exposure to the light is the bleaching of the visual purple. This substance is found in the outer parts of the rods in a "dark" eye, can be extracted in solution by suitable means, and is rapidly bleached by exposure to light. An attempt has been made to connect the bleaching of the visual purple with the phenomena of blue sensation by König. This theory perhaps needs better confirmation, but the phenomena of visual purple are interesting chiefly as a suggestion of the possi-



(a) (b)

FIG. 7.—(a) "Light" Retina and (b) "Dark" Retina of Frog in Section, Showing Change in Position of Cones (c) and Pigment (p) (after v. Genderen-Stort).

bility of other colorless substances in the retina which, by their light sensitiveness, may play parts in light and color vision.

(b) **Retinal Functions.** What we have said concerning retinal structure leads us naturally to a question to be considered with reference to retinal functions. Our field of view with one eye is at any instant many times larger than the point we are looking directly at. The light sensitive area of the retina is just as many times larger than the part which is specialized for the resolution of fine detail. How, then, do the other functions of the retina vary over different portions of its area?

The visual field is measured by covering one eye and placing the other at the center of an arc (A, Fig. 8). The eye is fixed on one point of the arc (O), and the test object (B), whatever it may be, moved along the arc to find the exact point at which it is just visible. The arc is arranged to rotate about the visual axis (OA), and by repeating this observation with different positions of the arc the limit is obtained in every direction.

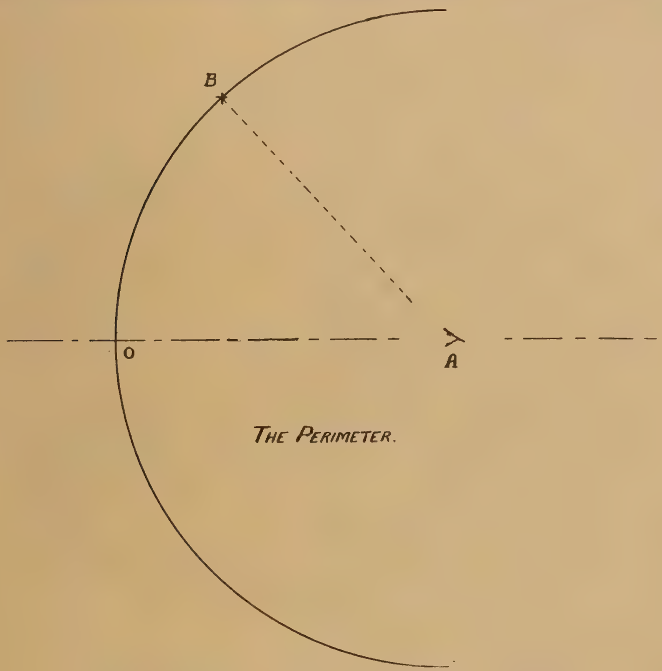


FIG. 8.—Method of Mapping the Visual Field.

The visual field for a single eye, as determined in this way, extends outward about 90° from the visual axis of that eye, inward 60°, upward 50° and downward 70° (Fig. 9). Within these limits light and form can be recognized to a variable extent. It must be understood that this applies to the fixed eye; movements of the eyeball, of course, will bring a larger area into view. For color perception, the area is less extensive and unequal for different colors. Blue has the largest field next to white, green has the smallest field of all, and red occupies an intermediate position.

Visual acuity, or the power to distinguish detail (such as the shape of letters) varies in a similar way. From the center of the

field it drops with extreme rapidity for a short distance, then more slowly, toward the outer part of the field (Fig. 10). For an eye kept in the dark and investigated in the dark by means of feebly lighted characters, the visual acuity, although of a low value, is about equal to that obtained under light conditions for the outer parts of the field, and is about equal for the whole field, except the center, where, under these conditions, vision seems to be reduced or absent.

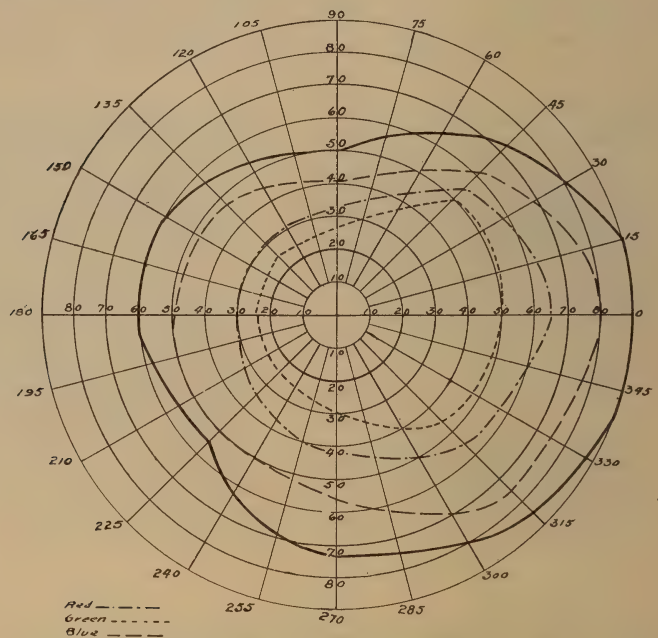


FIG. 9.—Limits of Visual Field for Form and for Color.

There is still another form of sensibility which we must consider under the head of distribution of function of the retina. A moment's thought will make it plain that our visual perception of movement depends on the sensibility of any given point of the retina to changes of intensity of the light falling on it, and must then go hand in hand with sensibility to "flicker." With respect to flicker the eccentric parts of the retina have been shown to have a higher sensibility than the center. In practical use, the outlying parts of the retina, as compared with the center, can then be said to distinguish objects better by their motion than by their form and color.

What we have just said concerning the distribution of the functions of the retina must always be borne in mind in what we are about to say in the analysis of the properties of the retina. In any investigation we must make use of a certain finite portion of

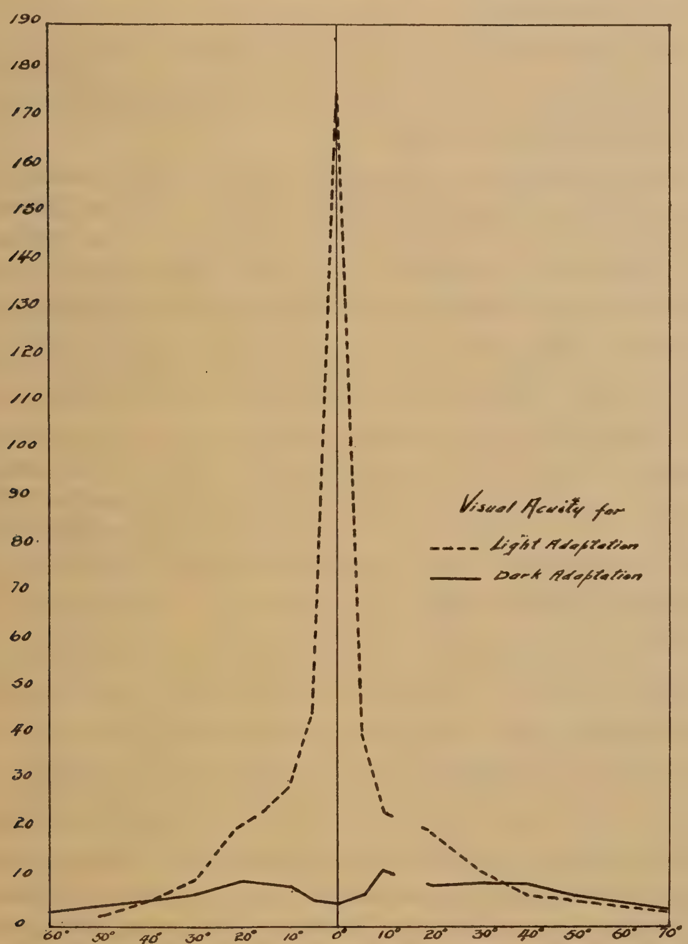


FIG. 10.

the retinal area, and this portion will certainly include portions of several zones of different sensibility values. A concrete instance of this is the comparison of two lights by the method of flicker photometry and by the method of visual acuity. As we just saw, the center of the retina is most acute as to resolution of detail, the

outlying parts most sensitive to flicker, so that in these two cases we may be using two different parts of the retina as the respective criteria of brightness, and the fact that photometry of different colored lights by the two methods does not give consistent results is not surprising.

This difference in the quality of response of the various parts of the retina must be borne in mind when we attempt to draw conclusions from the facts of color-mixture and allied questions, which we are about to discuss.

The simplest colors we have are the various monochromatic lights obtained by the dispersion of light from any ordinary light source by means of a prism or grating, and the exact results obtained in color questions have been obtained by this means. In color-mixture experiments the apparatus is arranged so that two different monochromatic lights may fall on the same part of the retina at the same time, and be capable of independent adjustment as to color and intensity. This is true physiological color mixture, and may be brought about in a less accurate way by the simple device of rotating a disc divided by radial lines into sectors of various colors, at such a speed that the disc shall appear of uniform color without flicker. We must stop here to point out one great difference between physiological color mixture and mixture of pigments. The mixture of pigments and the superposition of transparent colored media give approximately the same results. It is not in either case what can be called even a physical mixture of lights, since the resulting color is not the sum of the two in either physical or physiological sense, but is that portion of the whole white light common to the transmission of the two media. It is roughly white, less the sum of the absorptions of the two media that reaches the retina. A concrete instance of this is the well-known fact that blue and yellow pigments mixed make green; almost always a relatively dull green it must be said. Blue and yellow lights superimposed on the retina do not, however, make green, unless, indeed, we have chosen greenish-blue and greenish-yellow to start with, in which case we are able to get a very pale and washed-out green. With true blue and true yellow we are, however, much more apt to get a pale pink by physiological mixture.

The instance just given of blue and yellow is one of the most typical pairs of complementary colors that we could choose, that is to say, we can so choose a pure yellow and a pure blue that their

physiological mixture will produce the sensation of white without a trace of any color whatever. For our consideration a sufficiently complete list of pairs of spectral colors which produce white sensation when mixed is as follows:

Red	complementary to	Bluish-green.
Orange		Greenish-blue.
Yellow		Blue.
Greenish-yellow		Violet.
(Green		Purple.)

We see, then, that the complementary to red is bluish-green, and that from red to greenish-yellow the spectral colors all have complementaries in the region from bluish-green to violet. We have in this way accounted for the whole spectrum except the green region. Green has no complementary in the spectrum. For a complementary to it we have to use a mixed color, purple, made by combining light from the extreme ends of the spectrum, red, and blue or violet. It is possible, then, to arrange the spectral colors and the purples in a circle with purple occupying the gap between the final violet and the initial red in such a way that any diameter of the circle would end in two complementary colors.

More than this, we can imagine each diameter of this circle colored with the colors made by mixing the two end colors, graded uniformly from the one, through white at the center of the circle, to the other complementary at the opposite end of the diameter. If we do this in such a way that *any* straight line on the surface represents a series of colors made by mixing the same two colors, we have the "Farbentafel" or color chart, on which the spectral colors fall as shown by the curve in Fig. 11. This figure has, owing to its shape, been called the color triangle.

Of course, the area outside the curve corresponding to the spectral colors represents only theoretical colors. The apices of the triangle represent, respectively, the fundamental red, green and blue sensations of which we shall have more to say, and not actual physical colors. This figure is of value because it expresses many facts of color mixture. First, for a short distance, A to D (according to our assumption that a straight line falls on colors mixed from those at its extremes), we can see that intermediate spectral colors in this region can be perfectly matched by mixture of those on either side of it. Second, that this cannot be accurately done in any other part of the spectrum, but is most nearly true for the region from b to F (green to blue).

If we attempt to mix a green, however (E), we see that unless our two mixing colors already lie very close to E—really in the green—we cannot make a green by mixing them, but get, perhaps, a greenish color, very pale and close to the white. The same is true of red—we can, with blue or violet and orange, get a series of colors, rose color to salmon, resembling red, but all of them look pale compared with spectral red itself.

Finally, for blue the same holds, and these facts have led to the adoption of the three spectral colors, red, green and blue, as the

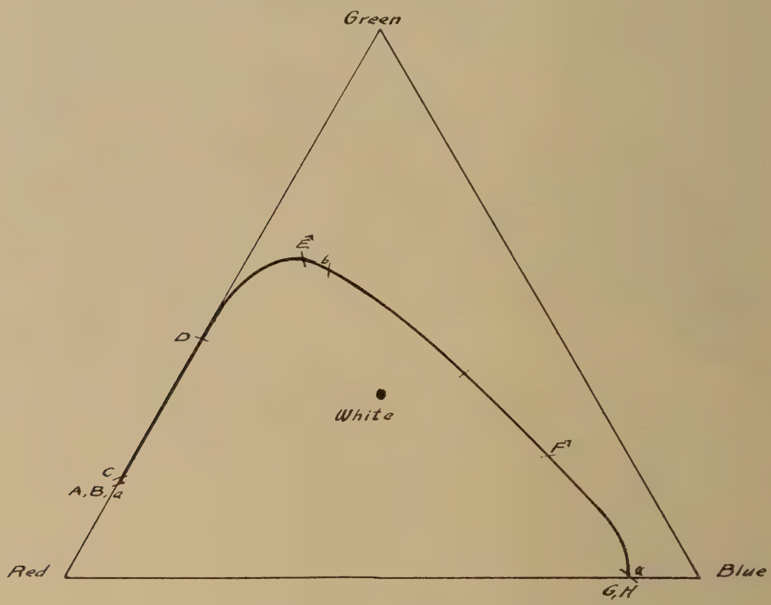


FIG. 11.—The Color Triangle (after König).

physical stimuli which respectively call forth with least degree of admixture the three physiological primary or fundamental color sensations.

Referring again to the diagram we see that starting with these, red, green and blue, we can with very little loss of saturation mix all the other spectral colors, the mixed color in general, however, always lying a little toward the white, i. e., a little paler than the nearest spectral color.

These facts have confirmed a theory as to color vision, originated by Young, developed by Helmholtz and his pupils, and at present

looked upon as expressing certain facts of color vision, especially of color mixture, and confirmed, as we shall see, by investigations in the color blind. In advance we must say that the suppositions involved in this theory are not proven anatomical facts. The theory supposes three different modes of response of the light-sensitive organs which have been spoken of as "three sets of fibers" or "three sets of cones." This, however, is only for the sake of brevity, and we will probably do better to avoid such expressions.

These three modes of response are distinct, however, just as they would be if they did depend on anatomically different structures, and when active give rise to red, green and blue sensations, re-

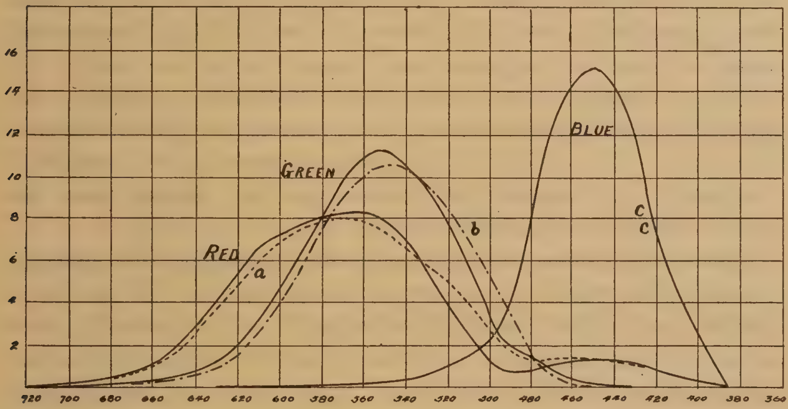


Fig. 12.

spectively. By the spectral colors they are, respectively, excited, as shown in the diagram (Fig. 12), by the three curves drawn in full lines. The ordinates of the three curves at any point show how the three fundamental sensations, respectively, respond to stimulus of monochromatic light of the corresponding wave length. It will be seen that for nearly the whole range of the spectrum, all three color sensations are active, but in varying proportions, from one end of the spectrum to the other. This means that no spectral light can, under visual conditions, excite one fundamental color sensation alone; in other words, the spectral colors are not physiologically saturated. We can, for instance, fatigue the eye by exposure to blue and red, and then the green of the spectrum will look more saturated than it did before.

In terms of this theory of color vision, white sensation arises when all three fundamental sensations are active at once, in certain balanced (for simplicity called "equal") proportions. Lack of saturation, then, is interpreted as admixture with white, that is, all three fundamental sensations are active, but not in "white" proportions. In as far as one or two of the fundamentals preponderate, the resulting sensation takes its hue or color from them.

This theory of color vision receives interesting confirmation by examination of the color-blind. Two classes of these cases, entirely distinct from each other, are the so-called red-blind and green-blind individuals. Their color curves are represented by the broken lines and the curve c in Fig. 12, in which the curves b and c represent the color curves of the red-blind eye, and a and c those of the green-blind eye. The curves, it will be seen, correspond closely to those of the normal eye, except that in the case of the red-blind individual the fundamental red sensation is absent, and similarly for the green-blind eye the fundamental green sensation is wanting. The slight differences seen between the respective "normal" and "color-blind" curves are not greater than the differences between different normal eyes.

There is another set of phenomena which bear on this question of color vision, that is, the question of after-images. If the eye is fixed on one point of a well-lighted object for a few moments, then turned to a gray surface, an indefinite image of that object can be seen which will last for some time. The colors in the after-image are in general complementary to those of the object itself, and light and dark parts of the picture are reversed. On the basis of the foregoing theory, this phenomenon is explained on the ground of fatigue of that part of the color-sensitive mechanism corresponding to the color of the object, so that when a colorless light is thrown on the retina the response of the previously (relatively) unstimulated and unexhausted mechanism predominates, and the sensation of exactly complementary color results. The reversal of light and shade is similarly explained; the parts of the retina on which the white light from the object falls are fatigued with respect to all three of the color components, with the result that they respond less actively than the rest of the retina, but that no fundamental sensation can predominate; therefore, the sensation resulting is simply dark with respect to the rest of the retina.

In a certain sense, then, brightness and darkness can be treated

similarly to a pair of complementary colors. Starting from this point, we may mention a second color theory which has held, and does hold, a place beside the one which we have just mentioned. In a certain sense we have just spoken of darkness and brightness as complementary colors. They are, too, in a sense, antagonistic, the one precluding the other. We can also choose from the spectrum two pairs of colors, such that we cannot even imagine, such a thing as the one of either pair partaking of the character of the other of that pair. These two pairs are:

(1) Red and green.

(2) Yellow and blue.

We can, for example, readily find such things as greenish or reddish yellow, but a bluish-yellow is not even thinkable. In this sense, then, these are pairs of antagonistic colors. Add to these the pair

(3) White and black,

and our three pairs represent the fundamental color substances of the Hering theory of color vision.

The first-named color of each pair represents, according to this theory, the breaking down of the respective color substance, the second a building up of the same substance. One process being caused by light stimulation of the retina, the other naturally follows, producing the after-image effect spoken of. It is easier, conceding the after-image as a reaction, rather than a negative result due to fatigue, to see why a complementary after-image should be seen in the dark, and why the after-image effect may be in some cases sufficient to suppress the still-acting stimulus which produces it. In the absence of all light the processes in the retina come to a uniform state of balance between building up and breaking down, which results in the sensation which is called "mean gray," and is not to be considered as black. The sensation resulting from a black spot in a white surface is indeed much blacker. In terms of this theory, the white-stimulated parts of the retina are, when a black spot on a white ground is looked at, the seat of a very active breakdown of the black-white substance. In response to this call, everywhere in the retina there is a more active building up of this substance as well in the part corresponding to the spot as elsewhere. Hence, the increase of blackness of the spot over absolute physical darkness. In this way, perhaps, this theory accords with the phenomena of contrast better than the three-color theory. The accentuation of differences at the common boundary

of two surfaces, a phenomenon referred to contrast or induction, falls in very well with its assumptions. Another similar phenomenon is that of the two equal gray figures on black and white grounds, respectively. They appear of different brightness in the opposite sense to the difference in their respective backgrounds. Further, these contrast effects are true of color differences as well as of brightness differences, and these the theory treats in a similar way, as we have seen.

We must here point out certain changes in color vision which take place when the illumination is greatly reduced. It is found that at sufficiently low illumination color disappears altogether. This range of illumination is called the "photochromatic interval." It is absent for those rays which are red at ordinary intensities. These are seen as red when seen at all. Below this point is a range over which the entire spectrum, as far as visible, is colorless. Apart from the absence of color, the conditions of vision at this low intensity are distinctly different from those at higher intensities, and vision under these conditions has received the name of "twilight vision." It is found that under these conditions the visible range of the spectrum has shortened, chiefly at the red end, and that the point of maximum brightness has travelled from the point it occupied at high intensities toward the blue end of the spectrum. This is an entirely different condition from the colorless vision of the peripheral areas of the retina at high intensity, where the relative brightness of the various parts of the spectrum has been found to be the same as in the case of the central color-sensitive parts of the retina under the same conditions. Further, it has been found that the totally color-blind eye (a third class of color-blindness, which we now allude to for the first time) sees the same brightness distribution as the normal eye does under conditions of twilight vision. In short, it has been stated that any eye which sees at all at these low intensities sees according to this same law of normal twilight vision.

This has led to a third theory of color vision called the "Duplicitäts-Theorie." This takes into account the differentiation of the light-perceiving organs into rods and cones, and their known behavior under changes in conditions of illumination.

It is a fact that under strong light the rods undergo a partial optical isolation through the migration of pigment particles into the spaces between them. The cones, as if to escape this, move

forward toward the light. Lastly, the visual purple which accumulates in the rods at twilight intensities is bleached under the influence of strong light. According to the duplicity theory, the cones are the active organs for color vision and for white vision at high intensities, and change their sensibility only slightly to compensate for variations in the intensity of illumination. The rods are incapable of supporting color vision, and report simple light sensation only. They increase tremendously in sensibility when the eye is kept in the dark.

If asked to choose between these three theories, it would appear that the last-described one assigns color vision to the cones alone, but does not appear to be antagonistic to the other two, the Young-Helmholtz and the Hering theories. Further, it might be said of these two, that one explains the facts of color mixture and color blindness the more satisfactorily, the other the facts concerning after-images, contrast, and so on. We must always remember that a theory is to be considered as the simplest explanation of known facts. As such it helps us to remember the facts. To argue from a theory to an unknown fact is risky. It helps us in investigation, but the unknown fact has to be substantiated by experiment before it can be accepted. The theory, however, often helps by indicating what we may reasonably expect to verify.

Lecture II

Special Applications

(a) **Photometry.** The question of photometry of lights of identical character is from the physiological standpoint a comparatively simple one. We might almost say (what is not strictly true) that there is no physiological question involved. The problem lies, however, more in the domain of physics, since identical lights must look alike to all eyes and be capable of measurement by all eyes that can see them at all; the individual variations, as in any other physical measurement arising from different degrees of sensitiveness and carefulness of observers, and not being inherent in the method.

When color difference enters the problem, however, the question is totally different, and we may well ask, in the case of wide differences of color, what right have we to estimate one in terms of the other at all? What common property is there that is possessed

by lights of all colors? The answer to this is not to be sought in physics but in psycho-physiology. Any light sensation, as was long ago pointed out, can be mentally analyzed as having three attributes, viz., brightness, color and saturation. A moment's thought makes it clear that these are, from the sensation standpoint, three distinct and separable qualities—yet when we try to hold them rigidly separate we are confronted by a very difficult or impossible task.

If we attempt to form a judgment as to equality of brightness by the simple inspection of two juxtaposed surfaces, we are met by the problem of this very analysis—we must distinguish between color and brightness, and mentally ignore the former to form a judgment. As to the feasibility of this as a photometric procedure we can only quote the words of Helmholtz, which I translate: "I must myself admit that I have never overcome a great uncertainty in these comparisons, although I do not believe myself to be inferior to other observers in the comparison of very small color differences at the same brightness and very small differences of brightness in the same color," and add that the frequency with which this is quoted only goes to show the frequency of its confirmation. Not only do different observers get different results, but those observers who can reproduce their own results at different times are so few and far between that the method has come to be looked upon as impracticable.

This has led to the suggestion of a second method of heterochromatic photometry: that two illuminations are to be considered equal when under them details, such as letters, figures or specially designed patterns, are equally visible. This proposition at first glance seems ideal. Although from the standpoint of its theoretical correctness it is open to objections, these are trifling compared with the difficulties of carrying out any accurate photometric measurements on the basis of equal visibility.

We have spoken of the variation of function of different parts of the retina. Let us briefly recapitulate. The center of the retina is at the fovea, a thin, rod-free portion of the retina, which receives the image of the object we are looking at. A silver quarter at arm's length represents its angular extent. At its border the rods begin to appear, as well as the pigment of the "yellow spot," which is of about three times the diameter of the fovea. The cones beyond this become fewer and larger, the rods coming to predominate.

At the same time we know that the color sense diminishes in acuteness as we go outwards, green, red and blue vision disappearing consecutively before the limit of the field is reached. Acuteness of vision diminishes tremendously as we leave the fovea and, finally, as to the perception of changes of intensity (flicker), the outlying parts of the retina are more sensitive than the center. In any question of heterochromatic photometry we may then justly raise the question as to what part of this diversely organized and variously sensitive organ called the retina we are to adopt as the criterion. A comparison of equal visibility must be made with the portion of the retina where visibility is at its maximum, that is, the fovea. A method of photometry which depends on the distinctness of vision of fine detail then depends on acuity of vision with reference to the center of the visual field.

A moment's consideration will make it evident that this, i. e., making possible the vision of fine detail, although an important function of illumination, is by no means its sole function. Exceptions are, for instance, general illumination, the illumination of corridors and thoroughfares. In the street the end sought is not the conditions of illumination for the best reading. On the contrary, what is the most important is not that at all, but the ability to distinguish moving objects not so much at the center of the field of vision, but more especially those objects not directly looked at. In crossing the street our safety depends on this very power of seeing moving objects by indirect vision.

This consideration, however, is not such an obstacle in the way of photometry by visual acuity as the difficulties inherent in the method itself. These are the result of several facts. The first of these is the fact that the increase of visual acuity with increase in illumination is very different for different eyes. The curves in Fig. 13 are from observations of König on different normal eyes, and show what variations we may expect from this reason.

Further, other factors, such as small errors in refraction or changes in the pupil, will outweigh large changes in light intensity. A small diaphragm (say about 2 mm. diameter) put before the eye, although at the same time cutting down the brightness of the retinal image, will usually increase the distinctness of vision.

Similarly, the ophthalmologist finds that the changes in visual acuity due to light variation are so small that they can be practically ignored, as compared with the changes brought about by a

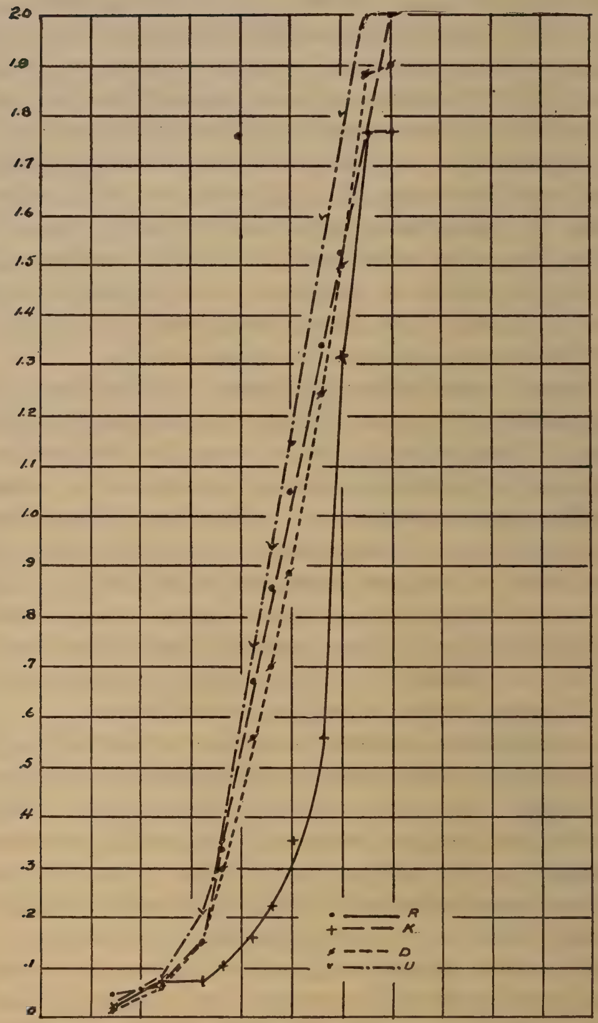


FIG. 13.—The Ordinates Represent Visual Acuity for Four Different Normal Individuals, the Abscissæ the Logarithms of the Illumination-Intensities. One Division in the Abscissa Line therefore Represents a *Ten-fold* Increase in Illumination (after König).

slight disturbance in the refraction of the eye. Then, too, it must be remembered that the eye is not optically corrected for color, that its constants are different for different colored lights, and that we are, therefore, practically working with a different eye when we work with different colored lights.

The final, and most fatal, objection to the visual-acuity method as a photometric method depends on two fundamental facts; the

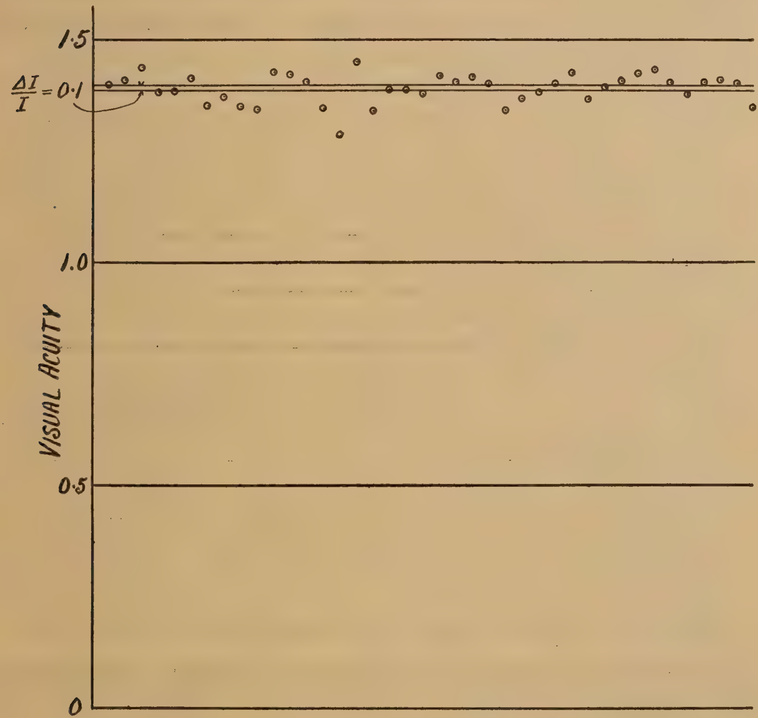


FIG. 14.

great uncertainty of observation, and the fact that visual acuity is a very slow-varying function of illumination. Fig. 14 illustrates a series of 40 observations, plotted serially, as taken under identical conditions. The test object was a system of parallel lines specially devised so as to admit of directly changing the width of the lines without altering any other condition, either distance, illumination or total flux of light; and, further, fluctuations of the pupil of the eye were shut out as far as possible by using a diaphragm of 2 mm.

diameter close to the eye. The irregularity was less in this series than in others taken in the same way; and this irregularity seems to depend on an absolute fluctuation from time to time of vision itself. The two parallel lines (running through the circles which indicate the values obtained) represent the change in visual acuity corresponding to 10 per cent change in illumination, as calculated from several series taken at widely different illuminations.

Finally, there is what is known as the "flicker" method of color photometry. The first-used form of this method was the

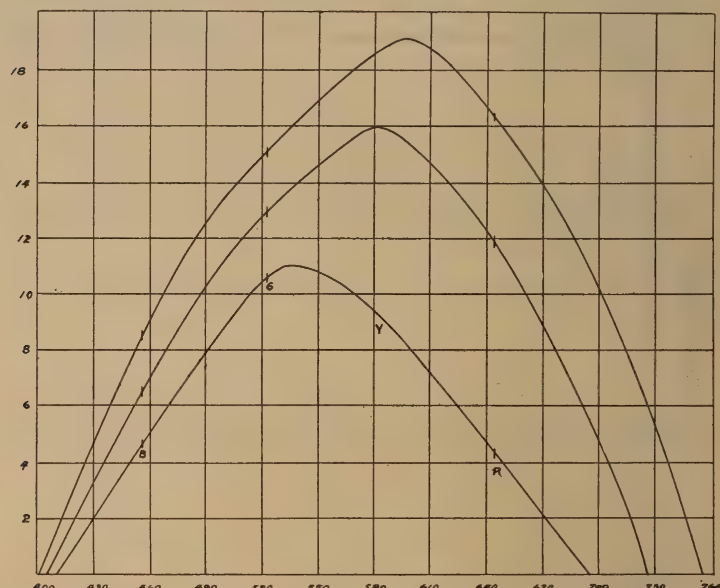


Fig. 15.—Critical Frequencies of the Spectral Colors at High, Medium and Low Intensities, Showing Relatively Greater Changes for Red (R) (after Haycraft).

simple determination of the frequency of alternation of illuminated and dark periods on a given surface, which was necessary to just abolish the flicker sensation, equal frequencies in the case of different colors being held to mean equal brightness. This has been used to determine the relative brightness of various parts of the spectrum and the changes caused by the general change of intensity from higher to lower, showing definitely that the phenomenon known as the Purkinje effect—that is, the disproportionately larger physiological brightening or darkening of the red end of the spec-

trum as compared with the blue, when the whole is physically changed in uniform proportion—is true for the method of photometry by critical frequencies.

The modern method of flicker photometry does not, however, measure light intensity by critical frequency. Briefly, the method consists in exposing the same portion of the retina to illumination from the two lights alternately. At a certain speed of alternation the two colors disappear, giving place to a uniform color with a flicker superimposed upon it. Then, when the relative intensities of the two illuminations are so altered that this flicker disappears, the two illuminations are by this method equal.

From the theoretical standpoint, it may be said that if it is possible in a light sensation to hold color and brightness apart as separable objects, that this method does it. We have a transition in the retina from one light stimulus to the other. After the two colors have ceased to be distinguishable owing to the speed of alternation, there is still a flicker which can be made to disappear by changing the relative intensities. In other words, color flicker has a lower critical frequency than brightness flicker, and on reaching this frequency we absolutely get rid of color difference and can make a comparison of brightness.

From the photometric standpoint this method has found warm adherents by reason of the fact that observations can be made with it to a degree of definiteness that has not been possible by direct comparison. The method permits of definite results, with a range of error far less, on the whole, than the other methods, and observations by the same observer under identical conditions are not subject to inexplicable variation from time to time as are those made by direct comparison. Finally, although the changes in results due to the absolute intensity at which the comparison is made are still found in this method, they are much less; and the same is true of variations in results due to the use of different parts of the retina (as in using instruments with different-sized fields) or the use of different retinae, as in the case of different observers, or (as is by no means unknown) by reason of difference in the sensitiveness of the two eyes of the same observer.

We have, then, a method for measuring two lights of different color against each other with a greater degree of certainty than other methods have done. Another advantage which must have great weight is the "satisfaction" of the observer in the observa-

tion itself. Direct comparison of two differently colored fields always leaves in the minds of most observers a feeling of uncertainty, a feeling of small confidence in the result obtained, which it is near impossible to shake off as long as the eye is disturbed by a color difference. In the flicker method the color difference is done away with, as we have shown, and the judgment is solely as to presence or absence of flicker.

While we may say, then, that the flicker method is subject to less variation than other methods proposed, and gives very definite results, consistent with itself, we must know that it is still subject to these variations with the others.

These variations can be explained only on physiological grounds. Physically, there is no such thing as brightness or equality of brightness. Physically, a given monochromatic light might be defined as a given quantity of energy in the form of radiation of a given wave length. At various wave lengths, however, the same energy has different brightness values, and these brightness values are not physical quantities, and are primarily not to be determined by physical methods such as the photographic plate or the selenium cell, nor by anything but the retina itself. Nor can we, accurately speaking, express the sensation-producing power for any wave length as a definite fraction of the sensation-producing power of any standard wave length, since, as a matter of fact, it has been amply shown that sensation increases with increase of energy by different laws for energy of different wave lengths.

We can only say that as the final criterion of equality of brightness is the response of certain retinal organs, and since these vary among themselves—not only in different parts of the same retina, but as well in the corresponding parts of different retinae; and further, that the identical retinal elements vary in their sensibility at different times and under different conditions, the question of heterochromatic photometry resolves itself into the question of standardizing heterochromatic light sources or color screens according to the judgment of a large number of normal eyes, so as to eliminate by standard apparatus the color difference. What are the normal eyes, and what is the best photometric method for such a standardization, are questions to be worked out. In brief, out of a large number of eyes those that agree the best with each other are to be considered as normal, and the best photometric method is the one subject to the smallest variations with normal eyes.

(b) **Glare.** One of the questions asked to elicit discussion at the January meeting of the London Illuminating Engineering Society was "What exactly constitutes a glaring system of illumination?" This question, at the outset, by the variety of answers it elicited seemed to indicate that the question of glare was not well understood, as well as the fact that the questions it involves are of great interest at the present day to those concerned with lighting problems.

While the exact definition of this idea of glare can well be postponed, it is at present proposed to give a very general definition to cover the meaning, and then, point by point, go over the question with this in view.

The definition we propose to use here is a paraphrase of the famous definition of dirt: "Dirt is matter out of place." We shall here define glare as "Light out of place." It is trite to say that light is essential to vision, that without light vision is not possible. We can, however, add that under certain circumstances light entering the eye (as when looking at objects beyond a light source) may be inimical to vision and enunciate a general proposition that glare is "embarrassment of the eyes or vision associated with strong light sensation." To see how this may come about it will be necessary to go into that side of the question which deals with living substance and its reactions, for the question is one which is well within the borders of psychology and physiology.

Here we have to distinguish two factors: First, that under certain circumstances, light falling into the eye may cause immediate pain. Second, that light may fall into the eye in such a way as to make vision difficult, so that although no immediate pain results, continuous work results in discomfort. As to the first, the immediate pain, there seems little to say. It is a familiar fact that a light can be too bright to look at, either absolutely, as the sun, or in a relative sense, as any artificial light which is bright enough to cause pain after a sojourn in the dark for an hour or so, but to which the eye can soon become accustomed. It is to be said that the intensity at which a light becomes directly painful is largely a relative matter. One condition on which this depends is the state of adaptation of the eye, an eye just out of the dark being much more sensitive in this respect.

The condition of the eye in which it responds abnormally to the light by the sense of pain is called *photophobia,* owing to the ap-

pearance of fear of light, as shown by forcible closure of the lids and attempts to get away from the light in extreme cases. There is a form of photophobia described which arises from exposure to light objects by reason of occupation, as in marble workers, etc., in which the sufferer finds himself much more comfortable working in a very subdued light. Further, in certain diseased conditions of the nervous system, and inflammatory disturbances of the eye, for instance, of the cornea, tolerance of light may be reduced to such a point that the use of the eyes is virtually prohibited, except at the lowest illuminations.

The second set of circumstances, in which light may be adverse to vision, takes place in such a way that, although there is no pain, the eye is obliged to work at a disadvantage. To understand how this may occur it will be necessary to consider a few points that we have already alluded to.

We saw that the eye, while it can in every respect be looked upon as a physical instrument, is something more than this, and we spoke of the muscular structures, namely, the ciliary muscle, by which the eye is optically adjusted for near and far vision, and the "extrinsic" or outside muscles, by which the visual axes of the two eyes can be turned so as to meet at the object looked at. We also spoke of the probability of finer invisible movements of the eyeball playing a part in vision of details just as slight movements of the fingers bring about a great increase in their power to feel the finer details of an object touched. The point in this is, that these muscular structures compensate, by rapid adjustment, any other defects of structure or environment under which the eye has to labor.

The defects of structure we have already mentioned. It can be seen how slight defects of refraction, a slight astigmatism, such, for instance, that horizontal lines are not in focus on the retina at the same time as vertical lines, will necessitate much more frequent adjustments of accommodation than are required in a normal eye doing the same work. Not only this, but the eyeballs themselves will have to be repeatedly turned back to look for details which were not taken in at first glance, so that all the ocular muscles have extra work thrown upon them. In this way, then, slight defects in the eye itself call for increased activity of its muscular structures to make the eye do its work.

It is not only defects of the eye itself which call upon this re-

serve energy of its muscular structures, but equally well defects in the conditions which it has to meet. Any circumstance which reduces the power of the eye to resolve detail, for example, dim light or flickering light, compel the muscles of the eye to do extra work. This situation can be summed up in simple words in some such way as this: When it is hard to see we have to look twice to be sure, and this extra strain on the muscles of the eye does often in the long run make trouble.

It remains, then, to consider this question: "What conditions in illumination associated with the idea of 'too much light' can make vision difficult?" And the reply is, light in the field of vision not from the object of vision, and of an order of intensity disproportionately large. The simplest illustration of this is the light source in the field of view, which cuts off the vision of objects of relatively low illumination beyond it.

There are three points to be considered when we wish to discuss the reason for the well-known disturbance of vision caused by a light source placed within the field of view.

A light source in the field of vision is always an invitation for direct vision. There is always a tendency to look directly at the light source. This is best seen in children, perhaps, but is nevertheless, even in those that habitually resist it, a potent factor in disturbing fixation of vision on the object we wish to look at. In this way, the same amount of light coming to the eye from a source of small area is much more of an object to fasten the attention than a large one. This can be shown simply by means of a lens in sunlight. A card held at varying distances will receive either a sharp image of the sun, or a large circle of light, in either case sending to the eye the same total amount of light, and it is quickly seen that of the two the small spot makes the larger impression on the eye, and is, therefore, a greater disturbance to the fixation of the gaze elsewhere.

The fact that a naked-light source of high intrinsic brilliancy, very much off to one side in the field of view, is a great annoyance when reading, which may be gotten rid of when we decrease the apparent intrinsic brilliancy of the source by a diffusing medium, leaving the source still in the field of view, may be accounted for in this way. The question of direct irritation and damage to the retina by these over-brilliant images enters in here, however, and will be discussed under another head. We must not forget that an

object with reflecting surfaces, such as a piece of machinery, will present to the eyes many images of the light source which itself may be well screened from the eyes. These images, although of a lower brilliancy than the light source itself, may be very disturbing to vision by reason of their situation near to the center of the visual field.

FIG. 16.

In a second way, much light in the field of vision has a direct tendency to obscure the details in the relatively less luminous parts of the field of view, as we can easily verify by the simple experiment already mentioned of looking at the objects beyond a light source. At the same time we recognize an apparent darkening of the relatively dark parts of the visual field.

There are undoubtedly two factors relative to the eye itself concerned here, which have to do respectively with the function of the retina and the dioptrics of the eye, and which have been assigned different degrees of importance by different investigators.

The first of these we have spoken of as induction, or the reciprocal action of the retina. It is that property of the retina which makes a dark object look darker the lighter its background is, and vice versa (Fig. 16). Another simple case of this is that of the juxtaposed gray stripes of progressive increase in brightness, each of which, instead of appearing uniform, as it is, appears lighter at the edge touching the darker band, and darker at the edge touching the lighter one (Fig. 17). In general, we may say that the tendency of the retina is to accentuate differences of either color or brightness in the surfaces of objects simultaneously seen, and this tendency is greater, the nearer the images of these surfaces are to

Fig. 17.—Showing Induction, each Band, Although Uniform, Appears Darker at its Right-hand Edge and *Vice Versa* in Contrast to its Neighbor.

each other on the retina, and is greatest at the line of demarkation. In the case just spoken of, the apparent darkening of the edge of the gray band is sufficient, under certain conditions, actually to obscure the vision of details at that point to a definite extent. Although in this way induction may diminish visibility, we can easily see that for exactly the same reason it helps vision by making the lines of demarkation between adjacent surfaces more distinct. Thus, it acts in a sense exactly contrary to certain defects of the eye, by which all bright objects would otherwise be surrounded by a halo of light due to the imperfect transparency of the optical media of the eye.

This subject we did not consider under the head of optical defects, because it seemed to have a more special application here. Much work has been done on the optical principles of the eye, its main refracting surfaces, the passage of the light rays and the formation of images, but much less has ever been said as to the light which enters the eye and travels other paths than those which lead to the formation of the principal image. In the whole discussion at the January meeting of the London Illuminating

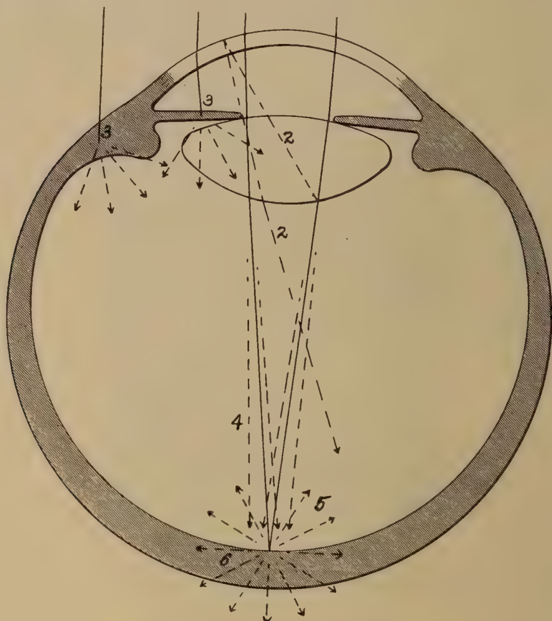


FIG. 18.—[The Figures Refer to the Numbered Paragraphs, pp. 562-3.]

Engineering Society, but one participant mentioned this question at all, Dr. Ettles, who spoke of the secondary image due to that portion of the light which undergoes double reflection between two refracting surfaces (instead of simple refraction). He considered this secondary image in the eye as playing a part in that embarrassment of vision called glare.

If we return to the question of structure of the eye we can distinguish the following significant points:

(1) We have first, the regular image on the retina, called the primary image, due to the passage of rays, with simple refraction,

from the object looked at to the retina, as shown by the full lines in Fig. 18.

(2) A set of secondary images, due to those rays reflected from the refracting surfaces, as we have already mentioned.

(3) Aside from this, we must consider that the wall of the eyeball and the iris are not perfectly opaque, and consequently afford a channel for a certain amount of light which is diffused within the eyeball.

(4) The media of the eye are not perfectly transparent, so that a certain amount of scattering of light takes place, which falls on the retina chiefly near the primary image.

(5) A considerable amount of light from the primary image is reflected from the surface of the retina and scattered within the eyeball.

(6) Light forming the primary image penetrating the retina is diffused through the tissues into which it falls in all directions, and some of it inevitably gets back to the sensitive layer of adjoining parts of the retina.

This stray light has the effect of obscuring vision of details in those parts of the retina on which it falls. This comes about in exactly the same way as a hazy atmosphere restricts the vision of details in a distant landscape. The picture is overlaid, as we might say, by a luminous veil, contrasts in the picture are thereby reduced and the power of vision restricted.

When we consider that in no less than five ways stray light gets into the eye, with the tendency to obliterate details that it must have, the question arises, not "Why is there such a thing as glare?" but "Why are we not troubled with it *all* the time?" The reply is, that quantitatively, the intensity of the stray light is not simply of a lower magnitude than that of the image, but is almost of a lower order of magnitude.

Consider in this connection, an ordinary living room lit, first, by bright sunlight; second, by diffuse daylight; third, by a modern domestic light source, and, fourth, by a single candle. A striking fact that will be noticed is that (at least after a short time in the room) vision will be almost equally good under any of these illuminants, except, perhaps, that of the single candle, when the remote parts of the room will be absolutely too dimly lit, and objects not well seen there. On the whole, however, the eye succeeds in adopting its own scale of light and shade for each case,

and faithfully reports to consciousness its findings in terms of that scale, so that its function is, within the limits outlined, almost independent of the absolute intensity of the system of illumination under which it has to work. This fact, while it makes the eye a most excellent organ of vision, for the same reason makes the unaided eye the poorest sort of a photometer.

We will see, if we try the experiment, that in the sunlit room it is totally indifferent whether the candle is lit or not, and we may place it anywhere in the room without disturbing vision; indeed, without knowing it is there after we have once forgotten it. Less striking, of course, is the indifference of the eye toward a modern light source under daylight conditions, but, similarly, it is true that we cannot know much disturbance of vision from it while daylight is present.

Even the candle, however, can seriously disturb the vision of objects lit by its own light, even though itself physiologically extinguished in turn by the sunlight.

This brings us back to the question of adaptation. Although it has been shown that the sensitiveness of the eye, as measured by the magnitude of the least perceptible light stimulus, increases on the average several thousand times by dark adaptation, yet the full sensitiveness of the eye is not developed until an hour has been spent in the dark, so that at any one instant the eye is not capable of interpreting more than a very limited fraction of this tremendous range of intensities. For example, a mat-surfaced paper, as white as possible, and another as black as possible, when actually measured by a photometer appear to reflect light under identical conditions in quantities respectively as 20 to 1. In other words, a surface, which in common language is called dead black, is physically 5 per cent of a pure white. It is true that below this we can recognize darker shades, as black velvet or a hole in a dark box make our black paper look very light, so we will have to extend the limits of the scale of light and shade that the eye is capable of at any one time to something more than this range of 20 to 1. Just what these limits actually are has never been determined; they are apparently not well defined, but it is sufficient to say that for a given state of the eye, with a given total light flux into it, there is an upper and lower limit to its capacity for distinguishing light and shade, beyond which everything looks the same; a brightness which cannot be added to by increasing the

physical stimulus, and a blackness from which nothing can be subtracted, and in which a certain amount of light otherwise measurable may be present without becoming visible.

To return to the subject of scattered light. It is just this question which determines the visibility of scattered light in the eye, and the question of interference to vision of details brought about by its presence. If its quantity is about the same as that corresponding to the lower limit of visibility at that time it is fair to suppose that it will not bring about any noteworthy disturbance of vision at that time. This is precisely the condition under which an ordinary well-lit field of view, with the light source *not in it,* presents itself to the eye. In all probability the greatest range of intensity in such a case is somewhere on the order of 50 to 1 (in what is called good illumination), and is well taken care of by the eye.

On the other hand, if the light source is in the field of view, it can be shown that the light flux from it which directly enters the eye is of the same order of magnitude as the total flux of light from the objects the eye is at the time engaged in seeing. It is not to be wondered at, then, that light scattered on the retina by the direct light in the eye under such conditions is of the order of magnitude of the general illumination of the retina, and can constitute a serious embarrassment to vision.

(c) **Injuries from Radiation.** Under the head of injuries due to radiation we have several affections to consider, involving various parts of the eye. Just what parts of the spectrum are responsible in the different forms of injury is a matter on which entire agreement has not been reached. One difficulty in the way of this is the fact that experimentally extreme intensities have been necessary to produce any tissue changes whatever, so that by the time we have by any means separated light of approximately one wave length, the intensity of the radiation is too much reduced to bring about experimental injury. Wherever we hear much speculation and many contrary views expressed we may know that knowledge is in a very unformed state, and the last two years in illuminating engineering circles have been a period which illustrates this. We have heard, for instance, the opinion expressed by one who should know better, that ultra-violet radiation must be considered harmful even in small amounts. What reason there was for holding such a view did not appear; presumably, it was because ultra-violet radia-

tion had been shown to be harmful in large amounts. The conclusion does not follow for ultra-violet light any more than it does in regard to any other condition influencing tissue activity. A man may take in a week, without harm, enough strychnine to kill him if taken in one dose. Likewise, in a week enough ultra-violet radiation might easily be supported to cause violent inflammation of the eyes if taken in the course of a half hour. So it would not be sufficient to condemn any kind of radiation for illuminating purposes simply to show that it contained radiation of a wave length that had been known to cause injury. It would also have to be shown that this was present in sufficient intensity to do damage.

What are the disturbances known to result from radiation?

At the head of the list stand inflammatory affections of the eyes and skin, known, respectively, as ophthalmia electrica and dermatitis electrica. These made their appearance in human history at about the same time as the electric furnace. This is essentially a gigantic electric arc, between two large carbon electrodes. Those who were exposed to the radiation from this source were found to develop the trouble we spoke of, in the eyes and in the exposed skin, especially of the face. The skin difficulty (dermatitis electrica) is not different from a severe sun-burn, except in its origin.

The symptoms in ophthalmia electrica begin a few hours after exposure with irritation of the eyes. This increases in intensity for 24 hours, during which time there is extreme pain and swelling of the eyelids, copious tearing and extreme light sensitiveness, and, finally, a free discharge becomes established. The discomfort then becomes less, the inflammation gradually subsides. In a week the eyes are practically normal, and in the skin which has suffered a certain amount of tanning is all that remains. This persists a few weeks longer. It must be remarked here that the inflammatory disturbances here spoken of are in the forward portion of the eye, not going deeper than the iris. Disturbances of the lens and retina we have to speak of separately. Ophthalmia electrica is now a well-established fact as a result of exposure to the radiation from the arc light, or to the quartz mercury-vapor light, in electricians, photographic coypists and others who are exposed to these light sources of high intensity, rich in light of the short-waved region of the spectrum. It always, as far as the present speaker knows, occurs at short range, and is almost invariably prevented if a layer of glass intervenes between the light and the eyes.

The flash from the short-circuiting of a large quantity of electric power causes symptoms similar to electric ophthalmia from the arc light.

Snow-blindness is similar in all essential respects to the disturbances we have just described. It occurs, as its name implies, after exposure to sunlight reflected from extensive snow-covered areas.

Associated with these, there have been shown to be disturbances of the retina. In the case of snow-blindness, a general disturbance of the circulation of pre-inflammatory or congestive nature has been observed. In the case of electric ophthalmia, disturbances over portions of the retina have been noted, in conjunction with either disturbance of color sensation or complete blindness of an isolated spot known as a *scotoma.*

In the case of short-circuit flash immediate blindness is a frequent result, usually of a few hours' duration, but which may leave vision permanently reduced or absent. Some of these local disturbances of the retina may, however, appear without the inflammatory changes of the forward part of the eye. Such a thing as red-blind scotoma (or spot) is known as occurring in railway firemen from looking into the fire. A temporary red blindness may be induced by flooding the retina with light from almost any light source, by suitable means; or by looking at a sheet of white paper in the sunlight for a few minutes; the red blindness is then evident in illuminations of lower intensity. Absolute blindness of a spot corresponding to the image of the sun has occurred from looking at the sun (as during an eclipse) without any sign whatever in the external parts of the eye.

Finally, we have to consider the crystalline lens. This body is subject to a change called cataract, which is characterized by white opacity, due to loss of vitality and shrinkage of its substance, which obviously is an obstruction to vision just in so far as it fills the pupillary space. In glassmakers, exposed to the radiation from molten glass, cataract is a frequent thing, but its relation to radiation is by no means established—indeed, it is held by some to depend on other conditions in the lives of these workmen. Other than this, cataract from exposure to light is a very rare occurrence, the fact having been established in only a very few cases.

With these various forms of disturbance in mind, we can see that the question of transmission of various eye media is an im-

portant one. We cannot, for instance, attribute disturbances of the retina to radiation which is absorbed in the cornea or the lens, yet an inflammation which locates itself in the cornea might well be the result of such radiation.

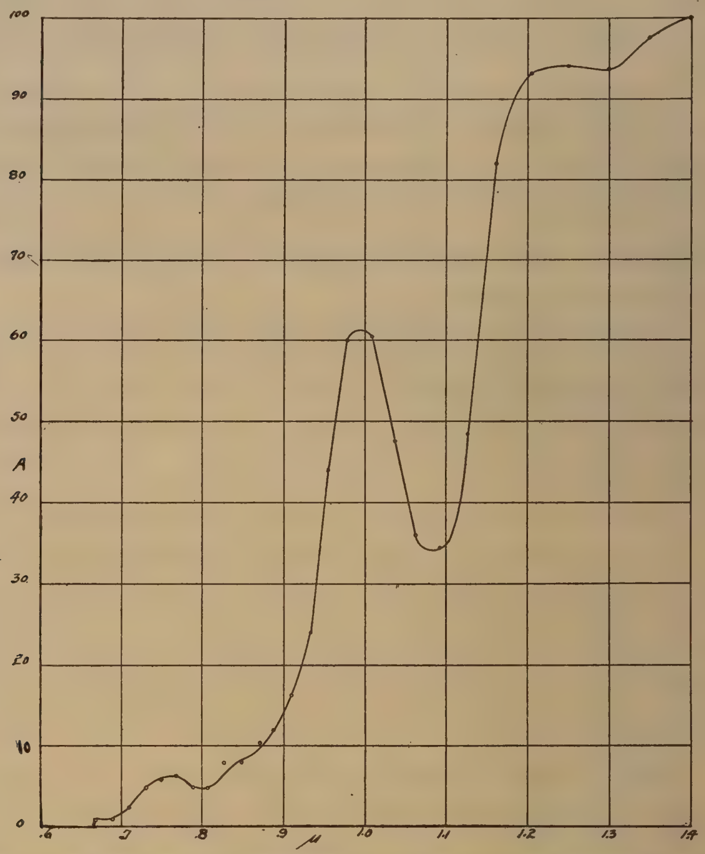


FIG. 19.—Absorption of Long-waved Radiation by the Eye-media (after Aschkinass).

Known radiations can conveniently be divided into three groups, the total range of visible energy being the middle one. Of longer wave length than this is the infra-red, and at the other extreme is the short-waved or ultra-violet radiation. We can assume, in general terms, that the media in the path of the light through the eye to the retina are permeable to the visible rays. Beyond this, in the infra-red, it has been shown that the eye media behave essen-

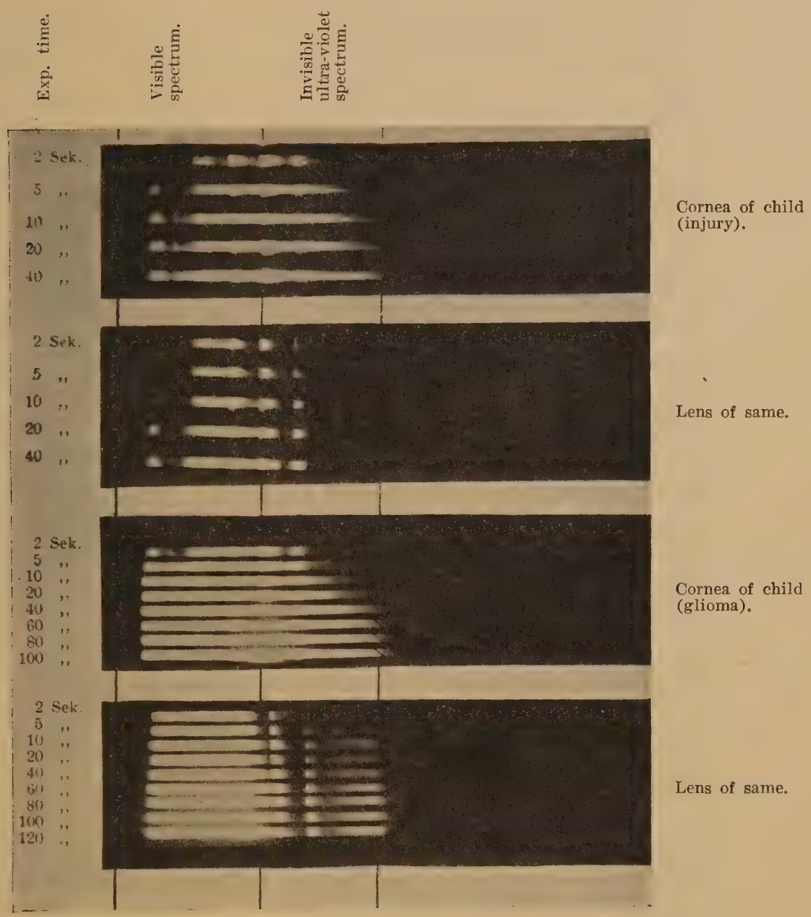


Fig. 20.—Photographic Absorption Spectra of Human Eye-media from Eyes Removed for Disease or Injury. The Media were Enclosed Between Quartz Plates and an Arc Lamp used as Light Source (Schanz & Stockhausen).

tially the same as water, at wave length 1.4 μ absorption is 100 per cent before the retina is reached, beginning to rise to this maximum from about the limit of the visible (Fig. 19). The transmission of the eye for ultra-violet is still more restricted. The cornea alone has about the same opacity for ultra-violet radiation as an ordinary spectacle glass, nothing of shorter wave length than 300 $\mu\mu$ passing through it. The lens again absorbs a large fraction of the energy from 300 $\mu\mu$ to the visible. The absorption seems to be considerable as near the visible as 385 $\mu\mu$, at least this is the spectral region which causes the lens to fluoresce the most strongly, and it has been shown that the energy from a magnesium spark, which lies chiefly at 280, 309 and 383 $\mu\mu$, penetrates a rabbit's eye as far as the lens, but no farther. Again, in the human eye, when the lens is removed by operation, the extreme violet of the spectrum becomes brighter than to a normal eye. We see, then, that the deep structures of the eye are inaccessible to radiation except the visible, and a limited margin beyond it in either direction. As far, then, as the retina is shown to be damaged by radiation we can hardly escape the conclusion that the visible energy is chiefly concerned. It is true that a complaint known as erythropsia (red vision), where everything appears red following exposure to strong light, is most frequent in eyes which have had the lens removed, and these rays, the ultra-violet near the visible, which it absorbs, are on this ground thought to be responsible for this disturbance. Erythropsia does, however, occur in the normal eye, and a transient form of it can be induced by the light from an ordinary carbon-filament electric lamp in which the ultra-violet radiation is a very small quantity.

Turning now to the anterior parts of the eye, on the assumption that the radiation passing through a medium unchanged cannot work changes in the medium, we are led to consider the infra-red and ultra-violet as possible causes of ophthalmia electrica and kindred disorders, since they are absorbed by the exposed parts of the eye. The possibility of the infra-red as a factor is almost ruled out by the fact that these disturbances were unknown from any artificial source of radiation until the electric arc came into use. When we consider in this connection the extent to which sources of infra-red radiation had been worked over in iron works and other industries, and the fact that artificial light sources were always relatively rich in infra-red up to that time, and yet no such dis-

turbance was known up to that time except from sunlight, it seems clear that the long-waved radiation beyond the red can have no material part in the disturbances of the superficial structures of the eye.

The ultra-violet, on the other hand, evidently does play a part in these disturbances. First, ophthalmia electrica, as its name implies, was not known until the electric arc came into use, a source rich in ultra-violet radiation down to very short wave lengths. Further, experimental investigation has shown these short wave lengths to have a very distinct influence on living cells and tissues of all kinds, from the bacteria up to mammalian tissues, this influence being shown by an increase of activity preceded by a "latent period" (of no change) of variable length and followed (if the exposure was severe enough) by depression of function and death of the living substance.

The conclusion is not far from this, that any source of light which emits radiation in the ultra-violet region is dangerous to the eyes. This by no means follows. It is, in the first place, unsound logic. Biological actions do not follow Newton's law; they are not proportional to the force impressed. We may, indeed, and usually do, find, that in the case of poisons, for instance, small and large doses will respectively elicit contrary effects; and that repeated small doses up to an aggregate, fatal if taken at once, may be totally without harm. More than this; by repeated doses a condition may be established in which enormous single doses can be taken with impunity.

We must consider these facts when we ask ourselves the question as to what are the wave lengths of the injurious ultra-violet radiations, and at what intensities these become pernicious.

It is unfortunate that accurately worked-out data in this important question are meager, for reasons mentioned, for as soon as we separate any radiation into its separate spectral components, we reduce the intensity of the radiation to a point where it is incapable of producing its physiological effect. The absence of such data has led to a rather hasty conclusion, that since ultra-violet light can produce harmful effects we must at once reject any light source which gives off any radiation whatever beyond the visible violet unless that same can be carefully screened off by suitable light-filter.

Before we are carried off by any such conclusion it is well to ask: what is the intensity and distribution of the ultra-violet radiations in any source of light of known harmlessness, as proven by experience, and how does this distribution compare with that of the suspected light source? The kind of light to which the eye has adapted itself in the course of centuries is daylight. But daylight is variable. It has been known to work injury. There is snow-blindness, a superficial inflammatory disturbance of the eyes; and sunburn, which is well known; these, as we saw, have been shown to be very exactly reproduced by the electric arc. They are, on the whole, not serious, a week's time bringing about a complete cure. Furthermore, snow-blindness with inflammatory symptoms, is very rare, always confined to high altitudes. Sunburn is well known; so also is the quick immunity to it that any part of the skin will develop on continued exposure. It does not need to be considered here. Neither does the list of eye and skin diseases that have been shown to do better if kept in the dark.

The essential point is, that daylight, except under extreme conditions and in exceptional instances, has been shown by several thousands of years of human experience to be not only harmless but indispensable. Sickness comes not by exposure to it but by the withdrawal of it.

If we start then with the assumption that diffused daylight at ordinary altitudes, in intensity not uncomfortably bright, is harmless—an assumption certainly true for normal human beings; the question of the harmfulness of any light from its invisible radiation will depend on whether, for equal visible intensity, the invisible radiation is at any point in the spectrum more intense than in the same part of the spectrum of average daylight as described.

Unquestionably, in the infra-red region our artificial sources are relatively much more intense than daylight, but the harmlessness of this radiation (apart from its direct heating effect, of which there is always ample warning) is proved by the years of experience of those who have worked exposed to tremendous amounts of radiation, strong in this region, in iron works and other industrial processes where large amounts of material have to be worked with at red or at so-called white heat.

As to the ultra-violet portion of the spectrum, and a good share of the visible, we have at hand the photographic plate, on which,

by means of a quartz optical system, we can get a permanent picture of the spectrum of any given light, which can be compared with spectro-photographs of other lights made under like conditions, so as to give us an approximate means of comparing spectral distributions.

In the hands of Hertel and Henker this method has shown that our incandescent light sources, including the tungsten filament and the gas mantle in their ultra-violet and short-waved visible regions, remain well within the limit of intensity set by our daylight standard. The naked-carbon arc shows a quantity of energy in the ultra-violet beyond this which is cut off practically to the "daylight" limit by a thickness of glass. The quartz mercury-arc shows a similarly extensive distribution of very short-waved energy which, with the exception of one line at 313 $\mu\mu$, is similarly cut off by a layer of glass.

These investigations confirm what common experience has shown, that modern light sources as used for general purposes do not work any damage to the users that can be attributed to their ultra-violet radiation. The injuries that have been experienced have always been with some very high-power light source at close range—either open arc or quartz-mercury arc without a glass screen, and the victim has usually been engaged in some technical operation in connection with the light.

The question is still to be answered, "Why is it that discomfort from the eyes is more common under artificial light than by daylight?" The increased use of artificial light in our modern civilization has, it seems, brought with it an increased amount of eye trouble. To what can this be due, if not to some quality of the artificial light? There are other things, however, to which we may attribute eye trouble, and one is increased demand on the eyes under modern conditions. No one doubts that we are, to-day, as a people, compelled to use our eyes more than our fathers did. With this demand on the eyes come two other things as natural consequences, namely, increased hours of work and increased use of artificial lights. Furthermore, work by artificial light comes almost invariably at the close of the day, when the worker and his eyes are in a state of fatigue, and demanding rest. Is it then to be wondered at that eye discomfort occurs chiefly while working by artificial light?

It is true that modern light sources are greatly abused. The flame of a candle or a kerosene lamp may be in the field of vision and not interfere seriously with the use of the eyes for close work. The carbon-filament lamp with no covering but clear glass is, however, already too bright to look at or to have in the field of vision, and the tungsten filament is somewhat more than twice as bright as the carbon filament; yet we frequently see these lamps installed in interiors in such a way that however we place ourselves one or more naked filaments are staring into our eyes.

The question of distribution of light for any given requirement is the important one. Fortunately, this question is receiving attention from illuminating engineers to-day. It is unfortunate that attention has been distracted from this to the irrelevant question of ultra-violet radiation. The problem is to bring about lighting conditions under which the eyes can work with the least wear and tear to them and their owners, and some of the details which enter into this problem from the physiological side we have in these lectures tried to make clear.

XII

THE PSYCHOLOGICAL ASPECTS OF ILLUMINATING ENGINEERING

By Robert M. Yerkes

CONTENTS

2. Laws of "seeing."
    a. Dual vision and the Purkinje phenomenon.
    b. Visual contrast.
        Of light.
        Of color.
    c. Visual adaptation.
    d. Visual after-images.
3. Practical bearings of the principles of "seeing."

IV. The agreeableness and diagreeableness of visual experiences.
1. The affective values of visual experiences are the resultants of three factors.
    a. The affective tone of visual sensations.
    b. The affective elements (sense feelings) of consciousness which regularly accompany sensations of light and color.
    c. The emotions and sentiments associated with "seeing."
2. The special affective, or feeling, values of experiences of light.
3. The special affective values of experiences of color.
    a. The psychology of red.
    b. The psychology of yellow.
    c. The psychology of green.
    d. The psychology of blue and violet.
4. The importance of affective values for the illuminating engineer.

V. Habit and custom in their relations to the values of illuminants and the problems of illuminating.
1. Laws of habit-inheritance, acquisition, association.
    a. Preferences for lights.
    b. Preferences for colors.
2. Laws of custom-convention, suggestion, imitation.

VI. The education of the individual and the race visually in the interests of the art of illuminating.
1. Science as basis upon systematic efforts to mould habits and customs.
2. The educative function and opportunities of the illuminating engineer.

I. The Scientific Basis of the Art of Illuminating Engineering

The ultimate goal of the illuminating engineer is psychological. He strives, with the highest attainable degree of efficiency, to produce desirable visual experiences in those whom he serves. The scientific basis of his art is tripartite: physical, physiological, and psychological. Knowledge of physical principles he employs, in the manipulation of illuminants, to produce and control certain physiological states of the organism; and knowledge of these physiological phenomena, in turn, he uses to help us to see. Little indeed should we care for the achievements of science and art in the production

and uses of light if, by reason of blindness, we were incapable of seeing! The practical successes of the illuminating engineer are conditioned, then, by his working knowledge of the facts and principles (1) of photic energy (the physical basis of illuminating); (2) of the bodily processes which are influenced by light (the physiological basis), and (3) of visual experience (the psychological basis).

This lecture is a sketch of the psychological basis of illuminating engineering. With the physical phenomena of light it has nothing to do; nor is it concerned with the bodily processes in the skin, retina, optic nerve, brain, muscles and glands, which are caused, or modified, by light. The phenomena discussed are those of consciousness—sensations, perceptions, feelings, judgments. In the interests of systematic discussion, the psychology of visual experience has been dealt with, in this lecture, under the following five heads: (I) visual elements of consciousness, visual sensations; (II) visual perceptions, complex experiences which are included in "seeing"; (III) feelings, emotions and sentiments, linked with visual experiences; (IV) principles of habit and custom in relation to "seeing"; and (V) the education of vision and "seeing." To each of these five topics a brief section of the lecture has been devoted, and an attempt to compensate for the necessary defects of the brevity of the discussion has been made in the list of references at the end of each section.

II. Our Systems of Visual Sensations

The analysis of human consciousness yields, among other phenomena, two systems of visual sensation: (1) the achromatic, or colorless light, sensations; and (2) the chromatic, or colored light, sensations. For the sake of convenience, we shall hereafter designate them simply as light and color sensations. Although these two systems of visual sensation are intimately and intricately related to one another, clearness of exposition demands that we at first examine them separately.

Our system of light sensations includes between six and seven hundred distinguishable qualities, all of which fall into three large classes; namely, sensations of white, of gray, and of black. It is a widely prevalent, but erroneous, notion that we experience only one quality of white and one quality of black. As a matter of fact, there are many sensations of white and of black, as there are

of gray. The black of the blackboard differs as strikingly from that of the inside of a light-tight box into which one peers through a small hole, as the white of a piece of crayon differs from that of a highly polished plate of silver in the light of the sun. Physically the word black is often used to indicate the absence of light, but psychologically it properly designates a definite and positive item of visual experience, not the absence of sensation. The sensation of black which one experiences as he gazes into a dark room is an element of visual consciousness in precisely the same sense as is the sensation of white which is experienced when sunlight is permitted to enter the room.

Our system of light sensations may be represented by a straight line. At one end of the line is located the blackest of our sensations of black; at the other, the whitest of our sensations of white; and between these two limiting points lie all the other qualities of black, gray and white which we experience.

Among human beings there are marked differences both in the range of the series of light sensations, and in the number of qualities which are experienced in a given portion of the system. Otherwise stated, some of us are capable of seeing farther in the direction of white or black, or both, than are other individuals. Thus we possess a larger number of qualities of white and black than are found in the experience of certain other persons. An additional reason for individual differences in the number of sensations of light is to be found in the fact that certain individuals are more highly sensitive to light than others and possess more refined powers of discrimination. It thus may happen that two individuals, whose systems of light sensations are limited by the same qualities of white and of black, experience the one four hundred and the other six hundred qualities of sensation between these extremes.

Attempts to describe sensations of light have brought to our knowledge a number of attributes which may be regarded as the essential properties of these sensations. They are (1) quality, (2) intensity, (3) clearness, (4) duration, (5) affective tone.

The *quality* of an achromatic sensation is its specifically individual attribute or property. It is that character by which we identify it and to which, provided it is of sufficient importance in our daily experience to justify the trouble, we give a name. Indeed, it is readily discovered that we have only three names for the more than six hundred qualities of light sensation which we ex-

perience. They are white, gray and black. Of light grays and dark grays we speak, but we do not even thus inexactly designate different qualities of white or of black. It is evident therefore that the terms white, gray and black designate classes of achromatic qualities, not single qualities. The same to be sure is true of red, of green, of purple, in chromatic sensation, and of many of our terms for odor qualities.

The *intensity* of a sensation of light is its attribute of strength or amount. A certain quality of white, or of black, may be experienced in one or in many intensities. We describe it accordingly as more or less bright. Taking, for example, a familiar quality of white sensation, I observe that it is experienced by me in several degrees of brightness, and I, therefore, in comparing the intensities of these sensations of white, speak of one as duller or brighter than another. It is important to note, at this point, that certain qualities, or lightnesses, of achromatic sensations are intrinsically of high intensity (brightness) whereas others are of low intensity. The qualities of white sensation usually are of high intensity, although there are noteworthy exceptions; those of black are usually of low intensity.

Following the usage proposed and adopted by Professor Titchener, we shall use the terms lighter-darker to describe the qualitative difference between two sensations of light, and the terms brighter-duller to describe their difference with respect to intensity. Confusion of lightness and brightness in accounts of our system of light sensations is the rule, and it is therefore difficult to read the psychological literature on vision without perplexity. It is highly desirable that we adopt a definite terminology which is both consistent with itself and in agreement with the psychological facts, and to this end I wish to urge the desirability of careful consideration of the merits of Professor Titchener's terminology.

The attribute of *clearness* is the attentional value of a sensation of light. It is its compellingness. Whereas certain sensations are clear-cut, definite and distinct, others are vague and hazy. Among the qualities of black which I almost daily experience, I observe that some are especially interesting to me because of their intrinsic clearness, whereas there are others to which I find it difficult to attend because their haziness annoys me. Even more strikingly, this difference in degree of clearness appears between sensations of taste, of smell, and of touch.

It is easy at first to confuse clearness with intensity. They are, however, distinguishably different attributes, albeit not mutually independent, for in general the moderately intense sensation is clearer than the extremely weak or the extremely strong sensation.

The *duration* of a sensation of light is its life-span or history. A particular quality and intensity of white runs a course in consciousness which may differ radically from that of another quality of sensation, or even of a different intensity of the same quality. Some achromatic sensations break into the stream of consciousness suddenly, remain for an instant on the crest of the wave of attention, and are gone; others appear more slowly, retain their maximal clearness for a longer period, and more gradually disappear. It is quite easy to note these and other differences in the duration of the various phases of a sensation of light.

Finally, of the fifth of the essential attributes of sensations of light, the *affective tone,* it must be said that there is disagreement among authorities as to the fact of its existence. In common with certain other psychologists, I include it among the essential attributes of sensation because my introspection furnishes me with evidence of its existence. It may be simply defined as the property of pleasantness or unpleasantness, or the feeling value, of a sensation. One quality of gray as compared with another quality may be the more pleasant, and the most searching introspective examination of this pleasantness may fail to reveal its independence of the sensation of gray.

The achromatic system of sensations, with its six to seven hundred distinguishably different qualities of light, each of which possesses the essential attributes of quality, intensity, clearness, duration and affective tone, is obviously of prime importance in our visual experience. Lacking what is commonly termed white-light vision, we should be in sad plight, for the greater part of our seeing is dependent upon precisely this sort of experience. It seems unnecessary to say, therefore, that a thorough knowledge of the chief facts and laws of our system of light sensations is of importance to the illuminating engineer. In his art, as in all others, excellent results may be obtained by trial and error, in the absence of clear foresight and the ability to predict results, but it is to be remembered that blind experimenting, in the hope of achieving practical results, is enormously expensive of time and energy, and that the work of the artist is worthy of praise in the measure in which it is

directed by definite knowledge of the properties of his materials and of the ways in which they may be most effectively used.

Very briefly our system of light sensations has been described. We must now turn to a similar examination of the second of our systems of visual sensations; namely, our color sensations.

In addition to the system of light sensations, the normal adult human being experiences sensations which constitute the chromatic system. For many of the qualities of this system—and in this our color terminology differs radically from our light terminology—we possess names. Thus certain of the spectral color qualities are designated as red, orange, yellow, green, blue, violet. Of these the principal colors psychologically are red, yellow, green and blue. When the qualities of purple, which lie between the spectral colors of red and violet, are included our sensations of color (more exactly speaking, of hue) number approximately one hundred and fifty.

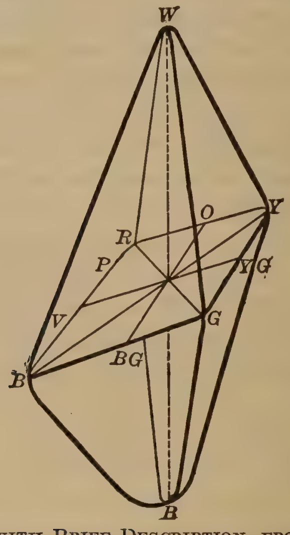
The attribute of quality in the case of sensations of light is simple, but in the case of sensations of color, it is complex. Analysis at present indicates that every sensation of color possesses at least three, instead of one, qualitative attributes. There is first, the quality of color, commonly so-called, or *hue,* as many psychologists prefer to call it. Thus red, violet, purple are hues. Secondly, every hue possesses the quality of depth or degree of color. This is often termed the saturation of the color. Professor Titchener has adopted the term *chroma.* Finally, a color sensation possesses a third quality, that of degree of lightness. It is either lighter or darker than another sensation of the same hue and the same chroma. For this quality, we shall use the term *tint.* From the point of view here taken, no qualitative description of a chromatic sensation is satisfactory unless it designates the hue, the chroma, and the tint of the sensation.

The qualitative attribute of tint or lightness of color sensations is frequently confused with the intensive attribute of brightness. As a given sensation of white may be lighter than another quality of white and at the same time duller, that is, less intense, so a given sensation of color, of green, may be lighter (of higher tint) than another color, and at the same time, duller.

For both the chromatic and the achromatic systems of sensation, the terms light-dark are here used to designate a qualitative attribute, whereas, the terms bright-dull are used to designate an intensive attribute.

All sensations of color, like those of light, possess also the attributes of clearness, duration and affective tone. Each of these characteristics of a color sensation is of considerable practical importance to the illuminating engineer, but we may not, at this point, add to what has already been said about them in the paragraphs on achromatic sensation.

Our system of color sensations, since it is, with respect to quality, tridimensional, cannot be represented by a line as can our system of light sensations. Instead, it requires a tridimensional figure. That of the double pyramid reproduced in the accompanying illustration most accurately represents the facts of color experience as they are at present known to us.



THE COLOR PYRAMID, WITH BRIEF DESCRIPTION, FROM TITCHENER'S "TEXT-BOOK OF PSYCHOLOGY," P. 63.

"At the two poles [of the double pyramid] stand the extremes of white and black; upon the vertical axis, between the poles, are arranged the remaining sensations of light. Round the base of the figure lie all hues of a middle tint and maximal chroma. Between the base and poles lie the same hues in all their further variety of tint; all are still of maximal chroma, though the chromatic maximum decreases steadily, above and below. If we cut into the pyramid, from any point on the outside to a corresponding point upon the axis, we lay bare a series of sensations of the same hue and tint, but of varying chroma.

"The double pyramid, then, as drawn in the figure, embodies the two systems of visual sensations, sensations of light and sensations of color, and shows these systems both in their mutual independence and in their mutual relations."

The existence of individuals who are totally color-blind proves that it is possible to experience sensations of light apart from sensations of color. The reverse, however, is apparently impossible, for we never experience color sensations without accompanying sensations of light. As I gaze at the paper before me, I become conscious of sensations of red and blue (lines on the white sheet) and of sensations of light (from the paper itself and the general illumination of the room). But however I may try, I never succeed in getting the sensations of red and blue without their accompanying achromatic sensations. This fact of visual experience may be briefly expressed by saying that our sensations of color ordinarily break in upon, or are superposed upon, a background of colorless sensations. It is therefore necessary for us to study our two systems of visual sensation in their mutual relations. The limits of this lecture, however, forbid the further discussion of the topic, and the reader must be referred to the list of psychological works at the end of this section for further information.

There are striking individual differences in the nature of color experience. Color defects range all the way from rare cases of total color-blindness, through cases of partial color-blindness, to slight subnormal sensitiveness to certain color qualities. As our knowledge of the facts of individual color experience increases, it becomes clearer that few of us are wholly normal with respect to vision. Certain of the individual differences which are commonly noted are, in all probability, to be correlated with age rather than with other characteristics of the individual. Thus, we discover that during infancy, sensations of light are of chief importance, while sensations of color are almost or entirely absent. Several years elapse before the child is capable of experiencing the sensations of the color system as does the average normal adult human being. In effect, then, we are totally color-blind for some time after we begin to experience sensations of light, and only gradually do we become capable of seeing colors. The infant, the blind individual, and the color-blind person are alike in that their visual experience lacks a large part of the qualities of sensation which you and I experience.

As has already been stated, color vision in the absence of white-light vision is unknown, and we therefore may not be called upon to imagine what our experience would be like if we saw colors without seeing lights. On the other hand, it is fairly easy to obtain first-hand accounts of the experience of individuals for whom colors

exist only as names used by other people. These individuals, as we well know, can get on very well in the world despite their visual deficiency, but they feel most keenly the limitations of their range of visual sensations, and they are prone to imagine that they are missing much that is of high affective value in consciousness. Just as no one who has once possessed vision will voluntarily give it up, so no one who has enjoyed the experience of living in a world of colors will willingly forego this satisfaction. There are undoubtedly charms in the lights and shadows, in the delicate and intricately related gradations of achromatic sensation, but it is only when these aspects of experience are supplemented by the multitudinous and richly affective sensations of color that we come into possession of the wealth of æsthetic experiences which come to those who can see colors as well as lights.

Were it not for the existence of color vision, the task of the illuminating engineer would be fairly simple and easy of accomplishment, and it is scarcely likely that this lecture would have been written. We do, in truth, strive for white light in our artificial illuminants, but we do this not because we wish to avoid experiences of color, but instead because we find it highly desirable to retain as completely as possible the variety and affective value of our ordinary color experiences by imitating as exactly as possible the natural illumination of sunlight.

Thus far we have dealt only with the constituent elements of visual experience—sensations of light and sensations of color—which psychological analysis has revealed to us. Of sensations of light, each of us experiences perhaps as many as seven hundred qualities; of sensations of color, we experience as many as forty or even fifty thousand qualities. For it is to be noted, that each of the one hundred and fifty hues which are distinguishable in the moderately intense solar spectrum and in the mixture of red and violet which link its extremes (the purples) may be experienced in a number of chromas, and that each of these chromas, in turn, may present itself in a number of tints. With fifty thousand, odd, sensations of vision at our command, it does not seem strange that our visual experiences should be complex, numerous, varied, interesting, and above all of supreme importance for our adaptations to environment and for our intellectual development and appreciations.

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III. "Seeing," or Visual Perception

The aim of the illuminating engineer is not to provide us with sensations of light and color but, instead, to enable us to *see,* and he succeeds in his art just in so far as he enables us to obtain clearly, agreeably, and serviceably those visual experiences which adaptation to our environment demands. Thus stated his task is purely psychological, and although he is constantly dealing with physical and physiological phenomena, his ability to use these phenomena in the interest of his art must depend upon his appreciation of visual experience.

The contrast between visual sensations and the concrete visual experiences which the ordinary man speaks of as "seeing" is important. For although it is quite possible to experience sensations of light and of color without seeing, this occurs only under exceptional conditions. Pressure upon the eyeball, direct stimulation of the optic nerve, or a blow on the head may be accompanied by flashes of light or by momentarily experienced sensations of color, but these visual experiences are both unusual and abnormal. Seeing is a vastly more complex process than sensing light or color. As I look out of the window, I see a tree. By this I mean, psychologically, that I experience certain sensations which belong to the achromatic system (certain qualities and intensities of gray), and certain others which belong to the color system (browns, greens, yellows), and, in connection with these, certain feelings of agreeableness or disagreeableness, certain images and ideas. The sensations are closely related, and they form what we may call a visual pattern. It is this pattern which I call a tree, and describe as of a certain size and shape, as gray of trunk, green of leaf, and yellow of blossom, for each of my several visual sensations has its definite place, or relations, in my total consciousness of the tree. Should the illuminating engineer so illuminate the tree that my

visual sensations were isolated, as are those flashes of light which accompany pressure upon the eyeball, I should not *see* the object, and the illumination would, therefore, be pronounced unsatisfactory. Or, should he so illuminate the tree that instead of appearing as it does in sunlight, the lights and shadows were reversed, the green leaves made to appear red and the yellow blossoms blue, the effect would be equally unsatisfactory.

In view of these considerations, it is evident that in seeing we wish to become conscious of certain characteristics or properties of what we ordinarily speak of as our environment. Through visual perception we become conscious of (a) the size, (b) the form, (c) the qualities of light, (d) the qualities of color, (e) the movements, (f) the distance or location, of objects. Vision, to be sure, does not give us our complete awareness of these characteristics of objects; it does, however, contribute an important factor in each case; hence, we speak of visual perception of movement, of distance, of size, of form, of light, of color. Indeed, it is precisely the appreciation of these features of things that we value and seek to attain through visual perception. The perceptual process involves the relating of elements of consciousness with one another so that they constitute more or less complex yet apparently homogeneous experiences.

Now, there are certain fundamental principles and laws of perception which are of significance to the illuminating engineer and which should be used by him in the solution of his problems. It will be utterly impossible in the course of this lecture to formulate all of the visual laws of which we should have knowledge, but we may at least present a few examples.

One of the most fundamental of recently ascertained principles of vision is that of the duality of the sense. It is now well established that our experiences of light and of color in daylight illumination differ markedly from those in twilight illumination. We may, therefore, speak of daylight vision and of twilight vision. In the fairly high intensity of daylight illumination, we experience the maximal number of achromatic sensations and the hues of the spectrum appear to us, as varying in brightness, with the region of maximal brightness in the yellow. In the rather low intensity of twilight illumination, we, on the contrary, experience fewer achromatic sensations, and the colors of the spectrum tend to become indistinguishable, with the region of maximal brightness in what ordinarily appears as the green. Briefly stated, in daylight

we possess both achromatic and chromatic vision, whereas in twilight our achromatic vision is limited as to the number of its elements and chromatic vision is either partially or totally lacking. This variation in the number and character of visual sensations with variation in the intensity of light is of extreme importance in connection with the practical problems of illumination as well as for visual theory.

It has been suggested, on excellent grounds of observation, that the sensory mechanism of the retina is dual, the rods functioning for both low and high intensities of light while the cones function only in moderately high intensities.

A second fundamental principle of visual perception is that of contrast. Two or more sensations appearing in consciousness simultaneously modify one another. If we look at a white page upon which a narrow strip of gray paper has been laid, the gray appears darker than it would apart from the sensation of white, and the white, in the immediate neighborhood of the gray, appears lighter by contrast. Thus each of the two visual sensations tends to emphasize the other. The law of contrast in its most general form may be stated thus: the contrast effect is always in the direction of the greatest qualitative opposition. Thus the contrast effect of white is black; or black, white; of light gray, dark gray. By taking account of this fundamental principle of visual perception, it is possible to avoid many undesirable effects in artificial illumination and to achieve desirable effects with directness and resultant economy. Not infrequently the problems of inside illumination force one to consider the nature of the background. There is, in such cases, the possibility of using it intelligently or of having it destroy in part the value of the illumination. If a room whose illumination is sufficiently intense for all practical purposes appears to be too dark, the illuminating engineer has failed to properly solve his problem, for those of us who make use of artificial illumination deal with situations as they appear to us, not as the photometer indicates, and my discomfort in having to read in an apparently insufficiently illuminated room is quite as annoying as it would be if the room were really insufficiently lighted. In practical life we all realize that it availeth little that the meter rod proves two columns of an otherwise perfect building to be equal in height if to our vision they appear disagreeably unequal. We blame the architect for his failure to take into account certain laws of perception—

architectural refinements we should call adherence to the rules laid down by a study of visual illusions. Similarly we blame the illuminating engineer who, in ignorance of the principle of contrast, so arranges his reflecting surfaces and his sources of illumination that the resultant light appears less intense than it should.

Inasmuch as the laws of color contrast are in several instances identical with those of light contrast, we shall consider the principles of both kinds of vision at the same time. Although a great many laws of contrast have been formulated more or less exactly by artists, and those otherwise practically concerned with the use of vision, we may cite as most truly indicative of the state of our knowledge of this matter the following five laws as formulated by Professor Titchener in his text-book of psychology:

(1) The contrast-effect is always in the direction of greatest opposition. Black makes its surroundings whitish. Red makes its surroundings greenish.

(2) The nearer together the contrasting surfaces, the greater is the contrast-effect.

(3) The contrast-effect is enhanced by the elimination of contours or boundary lines.

The following laws hold only of color contrast:

(4) The effect of contrast is greatest when there is no simultaneous light contrast.

(5) The effect of contrast increases with increase of the saturation of the inducing color.

To these five laws of visual contrast a sixth may be added, after the suggestion of von Bezold. It may be stated as follows:

(6) The cold, or short-wave length, colors (green, blue and violet) produce stronger contrast effects than do the warm, or long-wave length, colors (red, yellow and yellowish-green).

These generalizations from observation of our visual perception—and there are many others which should be stated if our space permitted—indicate certain fundamental characteristcs of our visual experience, ignorance of which has led many artists and manufacturers, as well as illuminating engineers, into serious errors of judgment. A typical example of these errors may be cited from the practical experience of the French chemist, and director of the dye works of the Gobelins, Mr. Chevreul. Mr. Chevreul * writes:

* Chevreul, M. E. The laws of contrast of colors (John Spanton, Transl.), London, 1861, p. 120.

"Ignorance of the law of contrast has, among drapers and manufacturers, been the subject of many disputes, which I have been happy to settle amicably, by demonstrating to the parties that they had no possible cause for litigation in the cases they submitted to me. I will relate some of these, to prevent similar disputes.

"Certain drapers gave to a calico-printer some cloths of single colors—red, violet and blue—upon which they wished black figures to be printed. They complained that upon the red cloths he had put green patterns; upon the violet, the figures appeared greenish-yellow; upon the blue, they were orange-brown or copper-colored—instead of the black which had been ordered. To convince them that they had no ground for complaint, it sufficed to have recourse to the following proofs:

I surrounded the patterns with white paper, so as to conceal the ground; the designs then appeared black.

I placed some cuttings of black cloth upon stuffs colored red, violet and blue; the cutting appeared like the printed designs, i. e., of the color complementary to the ground, although the same cuttings, when placed upon a white ground, were of a beautiful black.

"The modifications which black designs undergo upon different colored grounds are the following:

Upon red stuffs they appear dark green.

Upon orange stuffs they appear of a bluish-black.

Upon yellow stuffs they appear black, the violet tint of which is very feeble, on account of the great contrast of tone.

Upon green stuffs they appear of a reddish-grey.

Upon blue stuffs they appear of an orange-grey.

Upon violet stuffs they appear of a greenish-yellow grey."

The following table, also from Chevreul, is of value as indicating the contrast tendencies of the most important spectral colors, according to the observations of Chevreul:

Modifications Produced by Colored Lights

Red rays falling on	black	make it appear	purple-black.
"	white	"	red.
"	red	"	redder.
"	orange	"	redder.

Red rays falling on	yellow	make it appear	orange.
"	deep green	"	red-black.
'	light green	"	reddish-grey.
	light blue	"	violet.
	violet	"	purple.

Modifications Produced by Orange Light

Orange rays falling on	black	make it appear	maroon, or carmelite-brown.
"	white	"	orange.
"	orange	"	more vivid.
"	red	"	scarlet.
"	yellow	"	yellow-orange.
"	light green	"	yellow-green.
"	deep green	"	rusty-green.
"	light blue	"	orange-grey.
"	deep blue	"	grey, slightly orange-grey.
"	indigo blue	"	orange-maroon.
"	violet	"	red-maroon.

Modifications Produced by Yellow Light

Yellow rays falling on	black	made it appear	yellow-olive.
"	white	"	light yellow.
"	yellow	"	orange-yellow.
"	red	"	orange.
"	orange	"	yellower.
"	green	"	greenish-yellow.
"	light blue	"	yellow-green.
"	deep blue	"	green-slate.
"	indigo	"	orange-yellow.
"	violet	"	yellow-maroon.

Modifications produced by Green Light

Green rays falling on	black	make it appear	greenish-brown.
"	white	"	green.
"	green	"	more intense and brilliant.
"	red	"	brown.
"	orange	"	faint yellow, a little green.
"	green	"	greener, according to its depth.
"	indigo	"	dull green.
"	violet.	"	bluish-green brown.

Modifications Produced by Blue Light

Blue rays falling on	black	make it appear	blue-black.
Black "	white	"	blue.
"	blue	"	more vivid.
"	red	"	violet.
"	orange	"	brown, having a pale tint of violet.
Blue "	yellow	"	green.
"	green	"	blue-green.
"	indigo	"	dark-blue indigo.
"	violet	"	dark-blue violet.

Modifications Produced by Violet Light

Violet rays falling on	black	make it appear	very faint violet-black.
"	white	"	violet.
"	violet	"	deeper violet.
"	red	"	red-violet purple.
"	orange	"	light red.
"	yellow	"	brown, with a very slight tint of red.
"	green	"	light purple.
"	blue	"	fine blue violet.
"	indigo	"	deep blue violet.

In the practice of the art of illuminating, color contrast is even more important than light contrast, since most of our artificial illuminants are more or less colored. The effects of these illuminants are therefore complicated in accordance with the laws of contrast; and not infrequently, where the primary effect of a colored light would be agreeable, the final effect is by reason of contrast extremely disagreeable.

Chevreul, whose book on "The Laws of Contrast of Colour," although written early in the last century, is still of great interest and value, distinguished three kinds of contrast, to which he gave the names simultaneous, successive and mixed. The first of these varieties of contrast-effect we have already considered; and the second and third we may more properly consider under the headings adaptation and visual after-images. For what Chevreul designated as phenomena of successive contrast are really visual after-images, and what he designated as mixed contrast effects are phenomena which result from the relating of after-images to primary visual sensations.

The fundamental principle of visual adaptation may be stated thus: All sensations of light tend toward a middle gray and all sensations of color tend toward neutrality. We have all noted that we rapidly become accustomed to exceptionally strong or exceptionally weak light, to unusually colored lights, and to unusual combinations of light and color. In this we have observed the phenomenon of adaptation. Its effect is practically the opposite of that of contrast, for whereas it tends to abolish the differences of our visual sensations, contrast tends to make those differences more marked. Both principles are constantly gaining expression in our visual experience, but contrast at first predominates and only gradually does adaptation take its place. Thus, when I first look away

from a red light, the page to which I turn my attention appears greenish, whereas after a few moments it begins to lose its greenish hue and appears whitish or grayish. We here observe the phenomenon of successive contrast, or of the color after-image which follows upon the sensation of red, giving place to the phenomenon of adaptation in accordance with the law formulated above.

All of our senses exhibit adaptation more or less markedly, but in none of them is it more obviously important than in vision. Here it is a constant, although often unrecognized source of aid to the illuminating engineer, for were we forced to experience continuously or even for considerable intervals the primary and contrast effects of certain artificial illuminants and of their influence upon their surroundings we certainly should rebel. It is, indeed, a blessing that we are so constituted as rapidly to become accustomed to unnatural conditions of light and of color, or more correctly stated, to fail to see them as they really are and to see them instead according to our normal habits of vision. For colored lights which are disagreeable lose this affective value, not because their colors have gained new affective tones, but simply because we no longer see them as colored, since, according to the law of adaptation, they have become neutral.

We experience two kinds of visual after-images, called respectively the positive and the negative. "The positive after-image has the same relations of brightness as the stimulus, as in a photographic positive. The negative after-image has the relations of light and shade reversed, as in the photographic negative. The after-image may be of the same color as the stimulus, or it may be other-colored. There are positive same-colored and positive other-colored, negative same-colored and negative other-colored after-images. Generally, however, positive after-images are same-colored and negative other-colored are complementary.

"The positive after-image appears first and is usually very short in duration and difficult to detect. To make it conspicuous, one must employ a strong stimulus." *

Practically all intense visual sensations are followed by after-images, which, fortunately, seldom force themselves upon our attention. Indeed it is only the negative after-images of certain lights and colors that the ordinary observer notices. Occasionally, after

* Seashore, C. E.: Elementary Experiments in Psychology, New York, Henry Holt and Company, p. 7, 1908.

looking at a bright light, such as the sun, an electric arc, or a high candle-power incandescent, we become aware of a sensation of black, the negative after-image. Or, similarly, after looking fixedly at an intense yellow light for some seconds we notice, upon looking away, a sensation of blue as the after-image.

The several laws of visual perception which have been presented will serve to make clear the importance of this subject to all who have to deal with the problems of illumination. The principle of dual vision no less than that of contrast or that of adaptation should be taken into account when we strive for a particular effect of illumination. If our space permitted, we might point out in detail practical bearings of these and many other laws of perception.

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IV. The Agreeableness and Disagreeableness of Visual Experiences.

Our visual sensations and our visual perceptions are either pleasant or unpleasant, agreeable or disagreeable. This is a psychological fact which the illuminating engineer cannot afford to ignore, for illuminating means, among other things, the achieving of pleasing effects. This aspect of our visual experiences we may designate their affective value.

The affective value of a visual sensation or perception is the resultant of three factors: the affective tone of the sensation; sense feeling, or affective elements, of consciousness; and emotions and sentiments which happen to be associated with the visual experience. A particular sensation of red is pleasant because it has, for me, an agreeable affective tone; a certain sensation of purple is pleasant because it happens to be accompanied by a pleasant emotion, and in spite of the fact that its affective tone is decidedly disagreeable.

We may very briefly consider certain facts concerning the affective values of our two systems of visual sensations and of the perceptions in which one or the other of these types of sensation predominates.

In the case of sensations of colorless light, those which are medium in quality and intensity are as a rule pleasanter than the extremes in these respects. For example, the extremes of white and of black are less agreeable than the more frequently experienced qualities of these sensations; and the medium brightnesses of these sensations are likely to prove more agreeable than the extremes of intensity. From a series of grays, varying both in quality and in intensity, it is not difficult to select certain ones which are pleasant and certain others which are relatively unpleasant, and with practice one may even arrange them in order of agreeableness. In general it may be said that we prefer those achromatic experiences to which we are accustomed and which do not produce extreme fatigue.

But, in connection with the above statements, we must remember that our chance experiences of the emotional or sentimental sort in connection with lights are of tremendous importance. When I characterize the general illumination of a room as disagreeable, I am in all probability influenced as much by complex feelings and emotions which happen to be associated with the illumination as by the intrinsic affective attributes of the sensations of light which enter into my consciousness of the illumination. A dimly illuminated room may, for example, prove unpleasant because it brings to consciousness recent disagreeable emotional experiences in a similarly lighted sick-room. In this instance the emotional factor is far more important than the affective tone of the sensations in determining the affective value of the total visual experience.

Only by introspection can we discover the part played by the four contributory affective factors in a given experience. The affective tone of sensations of light is sometimes markedly pleasant or unpleasant, at other times practically indifferent; those affective elements of consciousness which are not dependent upon the sensations, but are relatively simple affective accompaniments thereof are sometimes conspicuous and at other times difficult to discover. The emotions likewise play very different rôles in connection with our visual experiences. At times, as sentiments they overshadow all other factors, and again, they are entirely lacking.

What has been said of light sensations applies equally to sensations of color, but the latter, by reason of their qualitative tridimensionality present more complex and manifold relations of the affective factors of experience than the former. We may therefore consider them separately.

For the illuminating engineer the affective values of red, yellow, green, blue and violet are of especial importance, since these are at once the principal color sensations of psychology and also the colors which give character to our artificial illuminants. The affective value of red must be considered, for example, in connection with the light of the low sun and of old and below-voltage incandescent lamps; that of yellow in connection with the light of the candle, the oil lamp, and certain incandescent gas and electric lamps; that of green in connection with the light of the Welsbach lamp, under certain conditions, and that of the mercury vapor lamp; that of blue and violet in connection with the light of the sky and of certain electric arcs.

Colors, to a far greater extent than lights, are accompanied by affective elements of consciousness, by emotions, and by powerful sentiments. We may not discuss each of these aspects of the subject separately, but we shall consider briefly the affective values of the principal colors. For we may not ignore the agreeableness or disagreeableness of visual experiences if we are in the service of the public any more than we may if we are seeking a stable scientific basis for the art of illuminating.

The psychology of red is peculiarly interesting because of the strikingly different effects which this color has upon different organisms and upon the same organism at different times. Red apparently promotes the life processes of plants, and violet seems to be essential for the normal existence of certain animals. Organisms which frequent the dark are partial to red; those which frequent the light seem to prefer blue. Red strongly stimulates certain organisms; notably, frogs, cattle, certain human beings. Moreover, in the languages of many uncivilized peoples, there are words only for the visual experiences of red, white and black.

There is a large and rather chaotic mass of information concerning the color sensations of infants, children, adults, uncivilized races, ancient peoples and abnormal individuals, as well as concerning the influence of colors upon organisms, but the interpretation and unification of these facts seem to wait upon a genetic theory of vision.

Of special interest to the illuminating engineer are the following points in the psychology of red. It is the common color of flowers, fruits, fire and blood. It stands thus contrasted with green and blue, which are the background colors of nature, the one of verdure, the other of sea and sky. It has natural value and highest usefulness apparently when definitely localized and in small amounts. As a hue for general illumination it seems ill suited.

According to the statement of Féré,* muscular activity as measured dynometrically was increased from twenty-three units in ordinary light, to twenty-four units by blue light, to twenty-eight units by green light, to thirty units by yellow light, to thirty-five units by orange light, and to forty-two units by red light. This is of interest when we consider that the color has at various times been a symbol of ritual, of war, and of love, and has been taken to signify cruelty, blood-thirstiness, courage, zeal, energy.

The lesson taught alike by the physiology and the psychology of red is that it should be avoided in general illumination, and used only for special purposes with full knowledge of its effects upon the organism.

The psychology of yellow is of peculiar interest because the majority of our artificial illuminants are yellowish. Savages and children are said to be fond of yellow and it seems probable that this attitude toward the color is the natural human attitude. Yellow is of high illuminosity and it lacks the peculiar, and not wholly desirable, stimulating characteristics of red. In parts of Asia it is the sacred color. It was made much of in Greece and Rome and it has been the delight of many other peoples as well as of certain individuals, who, as artists, have become strongly addicted to its use. It is perhaps significant that it is the color of the sun, under certain conditions, and that sunlight is often markedly yellow in hue. It is the color also of corn, whose attractiveness is noteworthy, of many ripe fruits, of amber, and of gold. With the advent of Christianity the reds, oranges, and yellows (all the strongly stimulating warm colors) were placed under a ban, and the colors of the blue end of the spectrum came into favor as symbolic of purity and submissiveness. Yellow became the symbol of jealousy and the mark of shame, and red shared more or less in this degradation. The prejudice against yellow and the other warm colors thus es-

* Féré, Ch.: Sensation et mouvement. Paris, Alcan, 1900, p. 43.

tablished prevails even to-day, and there can be no doubt that evidences of preference for yellow would be much more numerous were we not more or less directly influenced by the symbolism of colors in connection with Christianity.

In the contrast of our attitudes toward colors, we find splendid instances of chance agreeable or disagreeable experiences as well as of ingrained prejudices, and agreeable or disagreeable sentiments. We come to like or dislike colors much as we do taste or odor experiences, and it is sometimes extremely difficult for us to educate ourselves out of these acquired affective attitudes toward colors.

On the whole the affective value of yellow appears to be agreeable. For many individuals its affective tone is markedly pleasant, as are also its feeling and emotional accompaniments. There are indeed few contra-indications of yellow, for the purposes of illumination, from physiology, and those which come from psychology seem to be chiefly the results of a prejudice which is rapidly disappearing. Whereas an illuminant of distinctly reddish hue certainly should be used only for special purposes, a yellowish light may be used for general illumination with far less risk of unsatisfactory results. A yellow light is especially desirable where high illuminosity, warmth, and sprightliness of color are indicated.

The common practice of using yellowish illuminants gains justification and support from psychology, and there are reasons to suppose that further investigation of the psychology of color will still further strengthen the position of this color among those which are commonly present in artificial illuminants.

The color green is, under certain circumstances, very unpleasant; under others it is as markedly pleasant. In nature it plays an important role as the prevalent earth color, except in arid regions. Perhaps it is this very fact, and the habits of seeing and feeling which it has established in us, which renders green a disagreeable color for general illumination. The mercury vapor lamp, the old Welsbach, and all other sources of light of a distinctly greenish hue are more or less under disfavor. Their light is at first distinctly disagreeable to most individuals. But what is of chief interest in this connection is that there are circumstances which indicate the use of a greenish light. I have in mind an instance of excellent effects from the use of mercury vapor lamps. An automobile sales-room, which I have especially observed because of the agreeableness of the illumination, exhibits these lamps well placed and

efficiently as well as agreeably illuminating a space which because of its decorations would seem to be difficult of satisfactory illumination.

It is, of course, important to bear in mind that green, as compared with red, orange, and yellow, is a cold, restful color and may therefore be used for domestic or decorative illumination to very great advantage, provided pains be taken to avoid unpleasant results. Its high luminosity, when we are using our twilight vision, is of practical importance, and of this the illuminating engineer should take advantage.

Blue also is a cold, restful color. We shall consider it in connection with violet because of fundamental likenesses. Their luminosity is low, as compared with that of yellow and green, and they therefore make poor hues for general illumination. In general the effect of the use of blue and blue-violet lights is depressing. They are pleasant because of their restfulness and coolness, and for this reason may to advantage be used decoratively.

For certain individuals violet and purple lights in many of their hues, tints, chromas, and intensities possess unpleasant affective tones. The writer, for example, dislikes many violets and almost all purples, and on purely selfish affective grounds he would favor the discontinuance of all artificial illuminants whose light is strong in blue-violet. The light of certain arc lamps is for him peculiarly disagreeable, and certain dyes are equally unpleasant. But it would be unfair to condemn the colors blue and violet as hues for illuminants solely on the basis of individual affective value.

Psychologically, it is safe to say that violet is distinctly contra-indicated for general illumination, while blue is only less undesirable. This may seem surprising in view of the fact that sky light is strongly blue-violet, but it gains plausibility, albeit not justification, from the observation that the majority of our artificial illuminants are rather weak in blue-violet. It may be, therefore, that habit is playing a leading part in our present psychology of color. In fact this would seem inevitable, and the only question would appear to be, should we educate ourselves away from an actual prejudice against blue-violet illuminants? It is highly probable, in this connection, that the effects of different colors upon the appearance of the human face has much to do with our affective attitudes toward colored illuminants. This has been called to my attention in connection with an arrangement of the principal colors of our illu-

minants in order of preference by a number of skilled observers. I give the results below:

Observer A.	Observer R.	Observer E.	Observer H.	Introspection of Observer H.
Yellow	Yellow	Yellow	Yellow	Warm, neutrality
Red	Red	Green	Blue	Too cold
Green	Green	Blue	Green	Ghastly
Violet	Blue	Violet	Violet	Gloomy
Blue	Violet	Red	Red	Too exciting

Each of us possesses so many acquired emotional and sentimental attitudes towards chromatic sensations and complexes of these sensations that it is quite impossible for the illuminating engineer to predict the affective value of a particular color. He is therefore forced to consider individual tastes in illumination. A particular room, house, factory must be illuminated first of all in accordance with the fundamental laws of physics. But secondly, it must be illuminated also in accordance with the physiological and psychological characteristics of the individual or individuals for whom the work is being done. We should care as little about the work of the engineer who planned the illumination of our house without knowledge of our light and color preferences as we should for the tailor who insisted on making our suits without taking measurements.

The affective value of our visual experiences is a large and interesting topic upon which we have barely touched in mentioning a few of its aspects. Since few of our artificial illuminants closely approach white light in composition, the affective values of colors must constantly be considered side by side with those of achromatic experiences.

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V. Habit and Custom in their Relations to the Values of Illuminants

We experience sensations of light and color in variety proportional to our degree of visual development. We see what we expect to see, what our previous experience has prepared us to see, and we see in ways which have gradually established themselves. Our bents or prejudices with reference to visual experience present two aspects; that of nature or inheritance, and that of nurture or acquisition. And the latter is further analyzable into purely private and social acquisition. The relation of native disposition to visual experience we may dismiss with the bare recognition of its importance. The visually defective individual obviously demands special conditions of illumination. It therefore behooves the illuminating engineer both to know the normal visual experiences of men and to know how to meet such special demands as are made by over- or under-sensitive, by color-blind, and by perceptually or affectively atypical individuals.

Our ways of seeing are determined chiefly by two sets of conditions: our visual environment, and our fellow-beings. We see the world as a particular complex of light and color patterns because it is sunlit. How different would be our perceptions of it were it illuminated by a huge mercury vapor lamp! We first recognize, then approve, and finally come to like, or even to prefer to all other degrees or hues of illumination, that which prevails in our home, office, city, or country. These are only concrete ways of stating that we are, in matters of visual experience, no less than in matters of diet, creatures of habit and of custom.

Through the principle of habit, sunlight has gained a tremendous advantage over other sources of illumination. The fact is that each of us has learned, or is learning, to see—to perceive, interpret, understand, appreciate, think—things as they appear in the natural light of the sun. It requires a more or less prolonged and elaborate educative process for us to learn to get the same visual experiences

in an illumination which differs radically from that of sunlight. Consider the errors of perception and appreciation which we make when we view a landscape in moonlight. Much more numerous and more serious are those which we make when we see things in an illumination which is new to us.

To every change in the intensity or color of illumination we have to become adapted first by the fairly rapid process of immediate adjustment, and later by the more gradual process of habitation. It is because the acquisition of new habits of perception involves effort, waste, temporary mal-adjustment, that we sometimes object silently and again openly to marked changes of illumination. As we have grown accustomed to see our world, so we wish to continue to see it. Against this human tendency—and a valuable one it is—the innovator among illuminating engineers must work, for the majority of us have no special desire to learn to see things correctly in purple, or in green light. We are satisfied with sunlight as a general illuminant and we prefer to place the burden of labor upon the illuminating engineer by insisting that he discover for us an artificial source of illumination which is practically identical with sunlight in the quality of its light.

There is another and barely less important cause of human conservatism with respect to illumination. It is custom. What has been experienced by the individual finds its expression in his habits of mind, but so also, indirectly, do the experiences of parents, family, social groups, even the nation and the race. For we are creatures of custom as well as of habit. We are conventional, conservative, suggestible, imitative, all in varying degrees, yet each to an important extent. This tells in our visual experience. We are moulded in ways of seeing by our companions so that few of us ever come into full possession of our psychological individuality. We ignore, avoid, keep silent about experiences which have not been mentioned to us by our friends. In a thousand trivial ways we copy, imitate, follow out the suggestions of our elders.

If a new source of illumination, a new mode of decoration, or ornamentation can be made to conform to social convention, its success is assured, even though it be absurd because of disadvantages. Our modes of dress, social conventions, our architectural practices exemplify this tendency. A surprisingly large part of life is lived imitatively. Here, then, is our lesson in illuminating. What is, is not necessarily right, nor are the modes of

illuminating or the color experiences which are in favor generally or with a particular individual necessarily the best when all things are considered. The majority of us prefer sunlight in moderate intensity to every other condition of visual experience, and we would seem to have excellent physical, physiological, and psychological grounds for this preference. But my individual preference for the light of the tungsten lamp over that of the mercury vapor lamp may at any time prove to lack a reasonable scientific basis. Color preferences are, to a large degree, the results of our individual experiences, and so are many of our attitudes toward visual experiences, but there are, aside from these variable values of illuminating effects, certain general principles underlying visual consciousness which should guide us in the solution of the practical problems of illuminating.

Although the illuminating engineer should understand the taste of the individual, it is not his duty in any servile way to cater to that taste. Instead, he should look upon it as his chief social function and opportunity to educate the public visually in the interests of efficient illumination. This brings us to the sixth and last of the aspects of the psychological basis of illuminating engineering which we shall consider, visual education.

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VI. The Education of the Individual and the Race Visually.

The habit of working in illuminations which are too weak we recognize as bad. Nevertheless it is not rare. The habit of working—and of insisting that one cannot otherwise work satisfactorily—in illuminations which are too strong, is equally harmful and even more common perhaps than the other. Now, there is an optimal illumination with respect to light and to color for every

individual and for every situation in which that individual seeks visual experiences. One of the important demands made upon the illuminating engineer is that he correctly determine this optimal illumination and that he educate the public to an appreciation of the importance of regard for this best of all conditions for the use of vision. This is more than a matter of economy. It is a matter of health, of degree of visual efficiency, and of the affective value of experience. Who of us, for example, has not been annoyed, if not actually inconvenienced, by the high intrinsic brilliancy of our sources of light. My study desk is illuminated by a tungsten lamp toward which I may not look without having my visual sensitiveness markedly diminished and without experiencing an annoying negative after-image. This state of affairs cannot be excused nor in any measure justified by the fact that the sun is brilliant. For we aim no less to surpass or improve upon natural conditions of seeing than to imitate them. And at this point we must frankly admit that the ideal artificial illuminant may ultimately prove to be very different in quality and in optimal intensity from the light of the sun. Evidently we may expect of the illuminating engineer such placing of lamps as shall minimize the undesirable effects of high intrinsic brilliancy. If lamps of high intensity are to be used they should be hidden and so placed that their light shall be delivered diffusely and in adequate controllable amount to the space to be illuminated.

We are educable visually to an extent which few people realize. First of all, it is possible for us greatly to increase, by practice, our sensitiveness to white light and our discriminating ability. Secondly, the ability to perceive hues, chromas, tints, and intensities varies extremely among individuals and is largely dependent upon the amount and kind of use which the individual makes of his chromatic experiences. These facts are simply expressed by saying that the sense of vision may be improved by use. Education undoubtedly is of prime importance in connection with color vision, and it is highly gratifying to note the attention which is being given to systematic instruction in colors by our public schools. As Rood has said, "for the human race, thus far, light and shade has been the all-important element in the recognition of external objects; color has played only a subordinate part, and has been rather a source of pleasure than of positive utility." This is as true to-day, it would seem, as it was twenty-five years ago when the

above statement was written. It must be admitted that the state of affairs is unfortunate and that our color vision richly deserves more educative attention than it receives.

Education may deal profitably with visual perception. For, to quite as great an extent as in the case of our systems of sensation, practice and tuition enable us to gain serviceable ways of seeing. Each of us needs to learn how to perceive size, form, distance, as well as patterns in light and color.

There are also opportunities for education with respect to our affective attitudes toward visual experiences. The direction of attention toward the various values and practical relations of our visual experiences has much to do with our appreciation of them and with the development of our preferences and our prejudices. With the acquisition of definite knowledge concerning the practical and æsthetical values of lights and colors there come modifications of tastes. At present it is fairly certain that the common attitude toward yellowish illuminants is the result of habit and that many of us might readily educate ourselves to a like appreciation of certain chromas and tints of other hues.

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XIII (1)

ILLUMINATION CALCULATIONS

By Wm. E. Barrows, Jr., B. S., E. E.

CONTENTS

Lecture I

Determination of Mean Spherical Candle-Power and Illuminating Values

Lecture II

Illumination Calculations

LECTURE I

1. In order to be able to successfully perform illumination computations of various natures it becomes necessary to understand the several methods and underlying principles involved in obtaining the amount of light available for illuminating purposes. It is the prevailing practice to determine the candle-power at various angles around a lamp and in a plane through the source of light and to represent these results graphically and to scale upon polar coordinate paper. This polar diagram merely represents the value of the candle-power in different directions around the lamp and has no significance as a representation of the quantity of light. Thus

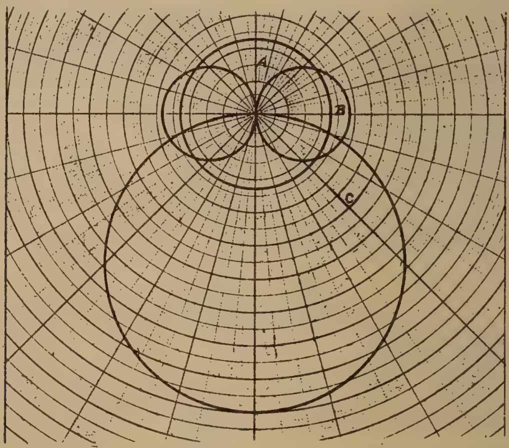

FIG. 1.—Distribution Curves Having Equal Values of Mean Spherical Intensity.

an interesting comparison, indicating the peculiarities of polar diagrams is shown in Fig. 1, where the three curves, A, B and C, represent theoretical distributions in a vertical plane. The maximum values in these three cases are approximately in the ratio of 15, 19, 60. However, if these curves represented distributions of light, from lamps, in a vertical plane the mean spherical candle-power or the total light flux would be the same for each.

2. The fundamental theory of this section of the subject is based on the study of spherical surfaces, in junction with which it is necessary to determine either the mean spherical intensity in candle-power, or the zonal or total flux of light in lumens. In these spherical calculations it is assumed that the luminous intensity is equal

in azimuth and varies only in one plane through the source which, in the following discussion, will be a vertical plane.

If we assume the source of light to be surrounded by a sphere of radius r with the source as a center, and further consider this sphere divided into a number of zones in such a manner that the illumination of similar parts of each zone is uniform, the total flux of light embraced by a zone will be equal to the product of the average intensity and the area of the zone. From a summation of these products for each zone the total value of light flux emitted by the source may be obtained and this divided by the area of the sphere ($4\pi r^2$) will give the mean spherical candle-power.

The light flux in the lower hemisphere will be the sum of the products of the zones and their intensities and this sum divided by

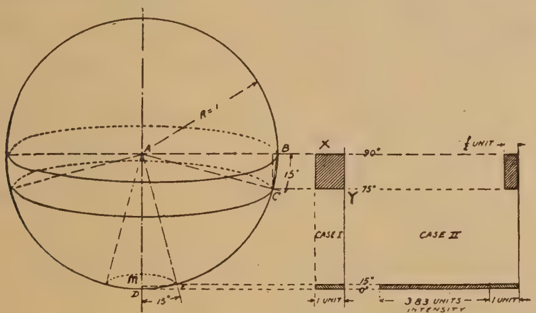

FIG. 2.—Relative Relations of Zonal Areas Shown Graphically.

the hemispherical area ($2\pi r^2$) will give the mean lower hemispherical candle-power.

The area of a zone subtended by an angle embracing the first 15° below the horizontal is 7.66 times as great as the area of the zone extending 15° from the vertical. With the same intensity in each zone, the total flux of light embraced by the former zone will be 7.66 times that passing through the latter. If now the source of light is of uniform intensity in all directions and by means of a reflector half of the light from the zone subtended by the first 15° below the horizontal be redirected downward through the zone extending 15° from the vertical, the intensity in the latter zone will be increased to 4.83 times its former intensity.

These results are shown graphically in Fig. 2 (2),* where case 1 represents the normal condition and the shaded parts the relative

* The numbers in parenthesis refer to the bibliography.

amounts of light in the two zones. Case 2 shows graphically the relative amounts and intensities of light in the same zones obtained by use of the reflector. Thus the quantity of light depends not only upon the intensities in the different directions, but upon the areas of the zones which the various intensities illuminate.

3. The area of a zone defined by the angles a and ada is

$$2\pi \cos a da,$$

and the quantity which it receives will be

$$\phi_1 = \int_{a_1}^{a_2} 2\pi I \cos a da,$$

a_1 and a_2 being the angles with the vertical which locate the meridians determining the zone. The mean intensity for the zone is equal to the total quantity of light flux divided by the area.

If the spherical surface is divided into n zones subtended by equal angles, then the total amount of light from the lamp will be

$$\phi = \phi_1 + \phi_2 + \ldots\ldots + \phi_n = \int_0^{0+\frac{\pi}{n}} 2\pi I_1 \cos a da + \int_{0+\frac{\pi}{n}}^{0+\frac{2\pi}{n}} 2\pi I_2 \cos a da$$

$$+ \ldots\ldots + \int_{\pi-\frac{2\pi}{n}}^{\pi-\frac{\pi}{n}} 2\pi I_{n-1} \cos a da + \int_{\pi-\frac{\pi}{n}}^{\pi} 2\pi I_n \cos a da.$$

If the intensity is uniform in all directions we have

$$\phi = \int_0^{\pi} 2\pi I \cos a da,$$

and the mean spherical intensity

$$I_{ms} = \frac{\int_0^{\pi} 2\pi I \cos a da}{4\pi}.$$

Unfortunately, the law according to which the intensity varies is too complex to allow the integration to be directly affected. Hence it becomes necessary to resort to methods involving approximations.

4. It can be shown by spherical trigonometry that the areas of the zones of a sphere are to each other as their altitudes. Thus the luminous flux in any zone of an imaginary sphere surrounding a source of light is proportional to

$$2\pi I(\cos a_1 - \cos a_2),$$

where $a_1 - a_2$ is the angle subtending the zone of reference, a_1 and a_2 being angles measured from the vertical, and I is the average intensity of illumination in that zone.

This equation forms the basis of the graphical methods of the Rousseau, Kennelly, Macbeth, Wohlauer and others for obtaining the mean spherical candle-power and luminous flux in lumens from a source having its distribution of light equal in azimuth.

5. The Rousseau diagram is the oldest of the various methods by means of which the mean spherical or hemispherical candle-power and the luminous flux as a whole or in part may be obtained. In its construction advantage is taken of the proportionality of the areas of the zones of a sphere to their respective altitudes. The values of the altitudes of zones subtended by equal angles are laid off to scale along the vertical axis of the diagram. These may be determined graphically, as shown in Fig. 3, where the sphere is

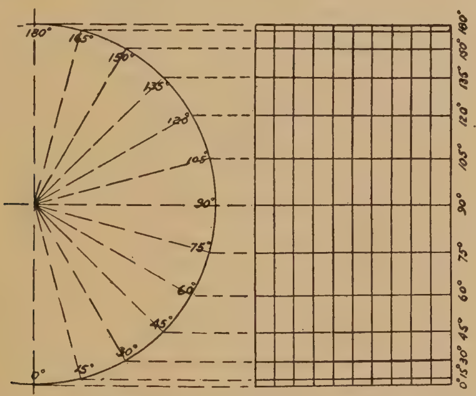

FIG. 3.—Construction of the Rousseau Diagram.

divided into 15° zones and the zonal boundaries projected on the vertical or by laying off horizontal lines at distances, to scale, from the center line equal to the cosines of the various angles as shown in Fig. 4. For every 10° in accordance with which Fig. 4 is constructed these values are as follows:

Degrees	0	10	20	30	40	50	60	70	80	90
Cosine	1.0	.985	.939	.866	.766	.643	.500	.342	.173	0

If, on the horizontal lines drawn from the terminals of the successive altitudes, we lay off to scale the values of the candle-power in the direction of the corresponding angles, then the area enclosed by the curve, determined by these values of the candle-power at various angles, and the ordinate, will represent the total luminous value of the source of light and the proportional part of the total light in any zone will be clearly shown. The value of this area in terms of

the product of the scales to which the curve was plotted divided by the sum of the ordinates will give the mean spherical candle-power and this value multiplied by 4π will give the flux in lumens. In the same way, areas corresponding to any zone or zones divided by the altitude or altitudes corresponding to the area will give the mean candle-power throughout the respective portion of the spherical area. To obtain the value of the mean spherical or mean hemispherical candle-power without a planimeter, the area enclosed by the curve may be divided horizontally by 20 lines bisecting areas of equal heights, Fig. 4. Without appreciable error we may assume

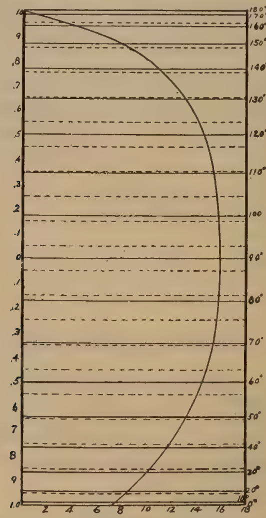

Fig. 4.—Construction of the Rousseau Diagram and Method of Determining the Mean Spherical Intensity.

that the average width of each section is equal to the distance across the middle of that section. Hence by reading the lengths of the horizontal lines shown dotted in the figure and by dividing the sum of their values by 20 we obtain the approximate value of the mean spherical candle-power. If the hemispherical candle-power is desired, consider only the areas corresponding to that hemisphere and divide the sum of the values of the dotted lines by 10.

The use of the Rousseau diagram for showing the relative light values of different sources is shown in Fig. 5 (6). The areas enclosed between the curves a′, b′ and c′, and the vertical on the right represent the total flux of light from three sources having

distribution curves as indicated by a, b and c, respectively. It will be seen that these curves are similar to those of Fig. 1, also that the three areas determined by the curves a′, b′ and c′ are equal. Since these areas represent graphically to scale the value of the light flux we have the same value of the lumens and mean spherical candle-power for each.

6. In the method of determining mean spherical intensities just discussed it will be seen that the spherical area surrounding the source of light was divided into zones of equal areas and the candle-power in the direction of the zonal centers of these areas assumed

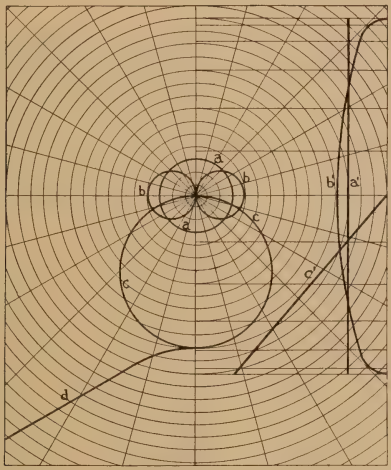

FIG. 5.—Rousseau Diagram Applied to Fig. 1.

as the average for that zone. This method forms the basis of Macbeth's "polar flux" paper, which is the ordinary polar co-ordinate paper on which are placed the radial lines representing the zonal centers of 20 zones of equal areas. The construction of this paper is shown in Fig. 6. The vertical distribution curves may be plotted as usual. The values of the candle-power read along these additional lines shown dotted in the figure, and the sum of these readings divided by the number of readings will give approximately the average candle-power throughout the zones which they represent. In order to use this method on polar curves constructed on ordinary polar co-ordinate paper, these radial lines may be drawn as in Fig. 7, on transparent celluloid of convenient size, to place over the polar curves. The values of candle-power may be read and the results determined as on the "polar flux" diagram.

7. The Kennelly diagram possesses the advantage of yielding the value of the mean spherical intensity in terms of a linear quantity. Moreover, only an angle protractor and a pair of compasses are necessary for its construction. This method consists in determining graphically an evolute from the polar curve of the luminous source, together with its involute and then projecting this involute upon a vertical line.

This method may be best understood by means of an example. In Fig. 8 is shown one of the common distribution curves for a tungsten equipment. The construction of the diagram is adapted to zones of 15°. Find the radii of the midzones, represented by the

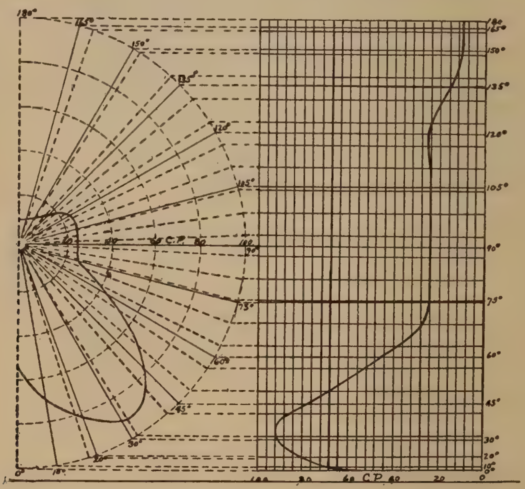

Fig. 6.—Construction of Macbeth's Polar Flux Paper.

dotted lines, oz, ou, ov, ow, ox, oy, respectively. Then with o as a center and with a radius oz describe the arc tz through an angle of 15°. Draw the radius ol from the end of this arc and measure from l along ol a distance la equal to ou. With a as a center and radius ou describe a second 15° arc so that ak makes an angle of 15° with al. Along ak lay off bk equal to ov and with b as a center continue the involute 15°. Draw bi, lay off ci equal to ow, draw arc ih and line hc, lay off hd, draw arc hg and line qd, lay off eg, draw arc fg, and line ef. The line ef should be vertical.

The method of procedure in the upper hemisphere is the same as in the lower hemisphere as indicated in the figure. Project the points f and f′ upon the vertical. Then half the distance mm′

between the extreme projections, to scale, is the value of the mean spherical candle-power, the length mo the mean lower hemispherical candle-power, and the length m′o the mean upper hemispherical candle-power. These values are approximately: mean spherical candle-power, 36.5; mean lower hemispherical candle-power, 52; mean upper hemispherical candle-power, 21. The total flux in lumens is 4π times the mean spherical candle-power, as in the other methods.

8. The fluxolite diagram devised by Mr. Wohlauer offers a convenient means of determining the luminous flux and spherical candle-power. The value of the flux is obtained by simply adding

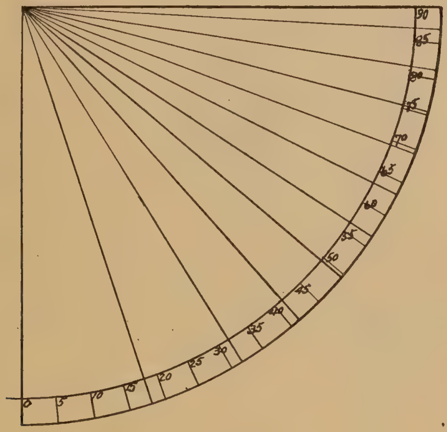

FIG. 7.—Disc with Radial Lines for Obtaining Mean Hemispherical Intensity from Polar Curves.

a number of linear dimensions drawn to scale and multiplying the same by some constant. This constant depends for its value upon the number of angular subdivisions of the spherical area.

It can be shown geometrically that the altitude and hence the area of a zone is proportional to the sine of the angle, measured from the vertical axis, which bisects the zone. Hence if the imaginary spherical area be divided into n numbers of equiangular zones and assuming the midzone intensity to be the average for the zone, then the flux in any zone will be

$$\phi = \mathrm{KI} \sin a,$$

where I is the average intensity of the zone, a the bisecting angle measured from the vertical axis and K a constant the value of which depends upon the number of zonal subdivisions.

Referring to Fig. 9 and representing the flux in successive zones from the nadir by ϕ_1, ϕ_2, etc., and the average intensities by I_1, I_2, etc., and the midzone angles by a_1, a_2, etc., we have

$$\phi_1 = KI_1 \sin a_1 = KL_{ab},$$
$$\phi_2 = KI_2 \sin a_2 = KL_{cd},$$
$$\phi_3 = KI_3 \sin a_3 = KL_{ef},$$

or

$$\phi = \phi_1 + \phi_2 + \ldots \phi_n = K(L_{ab} + L_{cd} + L_{ef} + \ldots, \text{etc.}).$$

Thus the flux in any zone is equal to the horizontal projection of its midzone intensity multiplied by the constant and the total flux in

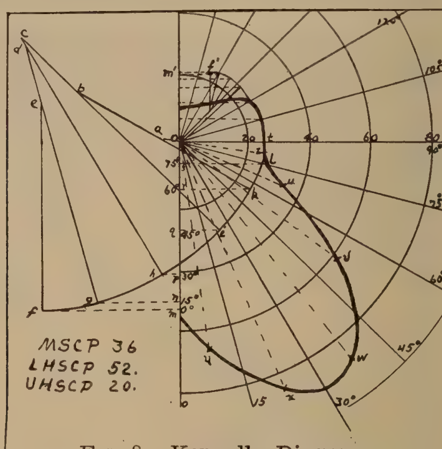

FIG. 8.—Kennelly Diagram.

lumens is equal to the sum of the several projections multiplied by the constant.

The mean hemispherical candle-power may be obtained by dividing the value of the flux in that hemisphere by 2π, and the mean spherical candle-power may be determined by dividing the value of the total flux by 4π. The values of K for various angular subdivisions are given in the following table:

Angle embrace of zone........	5	10	15	20	25	30
Value of K..................	0.548	1.098	1.64	2.18	2.72	3.25

In the example just cited K is equal to 1.64, a being equal to 15°.

The polar diagram is constructed with vertical lines spaced equal to the polar scale to facilitate the evaluation of the projections of the various midzone intensities.

By referring to the values of the constants given above we will see

that for zones subtended by 10° angles the value of K is 1.098. If now the polar curve, Fig. 9, was plotted on polar co-ordinate paper so dimensioned that 1.098 inches would equal some multiple of the candle-power, then the lumens could be determined directly by measuring the distances ab, cd, ef, etc., in inches and multiplying by the value of the multiple referred to above.

Since these constants refer to the relation between the candle-power scale and the scale of the distances from the vertical to the intersection of the midzone radial lines and the polar curve, it follows that for a certain design of polar co-ordinate paper one may

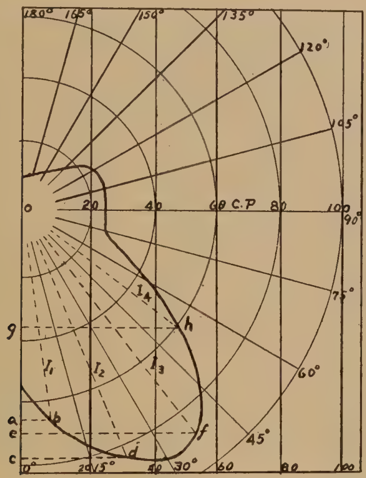

Fig. 9.—Wohlauer's "Fluxolite" Diagram.

construct a scale of convenient size and shape and graduated according to the above relation and with the common scale values indicated, whereby the flux in lumens may be determined for any polar curve on that design of paper. Such a construction is indicated in Fig. 10, which shows the polar flux paper and polar flux scale as designed by Mr. Macbeth. It will be seen that this scale ($\frac{3}{4}''$ by $5\frac{1}{4}''$) has eight sections to correspond to eight different values of candle-power per division on the polar paper for which the scale is designed. By choosing the proper section of the scale the distances from the vertical to the points a, b, c, etc., on the polar curve, measured by means of the scale, will equal approximately the number of lumens embraced by the corresponding zones. By continuing this process for the entire polar curve and adding the results the total flux will be obtained.

9. A method (6) of obtaining approximate values of the mean spherical or hemispherical candle-power or the luminous flux in lumens of the various zones, by means of an ordinary slide rule and set of constants will be found very convenient, especially where the results of photometrical tests are given in numerical values. These constants are calculated to correspond to a certain number of mid-zone directions in a vertical plane at which the candle-power is usually measured.

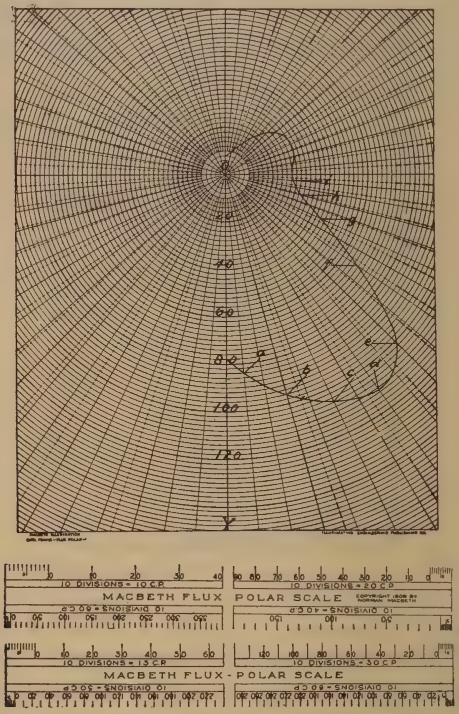

FIG. 10.—Macbeth's Flux Scale.

These values corresponding to every 15° from the vertical are as follows:

	Candle-power constant.		Flux constant.	
Cos 0° — cos 7° 30′	= .00856	× 2π =	.0538	for 0° from vertical.
Cos 7° 30′ — cos 22° 30′	= .06756	× 2π =	.424	for 15° from vertical.
Cos 22° 30′ — cos 37° 30′	= .1305	× 2π =	.820	for 30° from vertical.
Cos 37° 30′ — cos 52° 30′	= .1846	× 2π =	1.16	for 45° from vertical.
Cos 52° 30′ — cos 67° 30′	= .226	× 2π =	1.42	for 60° from vertical.
Cos 67° 30′ — cos 82° 30′	= .252	× 2π =	1.58	for 75° from vertical.
Cos 82° 30′ — cos 90°	= .1305	× 2π =	.820	for 90° from vertical.

By similar calculations those for every 10° from the vertical are

Midzone angles.	Candle-power constant.	Flux constant.
0	.00381	.0239
10	.03926	.190
20	.0596	.374
30	.0872	.547
40	.1120	.705
50	.1335	.841
60	.1509	.949
70	.1638	1.025
80	.1716	1.075
90	.0872	.548

Thus to determine the mean hemispherical intensity and the flux in the lower hemisphere proceed as indicated in the following table:

Degrees from vertical.	Candle-power.	Candle-power constant.	Component of M.H.S.C.P.	Flux constant.	Lumens.
0	8.0	.00856	.0685	.0538	.43
15	8.8	.0675	.594	.4244	3.73
30	10.6	.01305	1.383	.8202	8.69
45	13.1	.1846	2.418	1.1598	15.20
60	14.7	.2261	3.324	1.4205	20.85
75	16.2	.2521	4.080	1.5843	25.65
90	16.7	.1305	2.180	.8202	13.70
		M. H. C. P.	14.04	Lumens	88.25

It should be noted that these values of the lumens are for zones extending 7° 30′ above 0°, below 90°, and either way from the 15°, 30°, 45°, 60° and 75° directions.

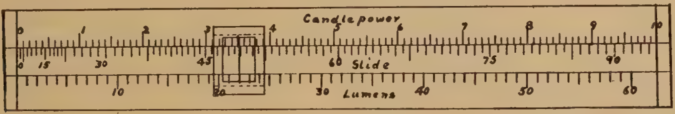

FIG. 11.—Slide-rule for Determining the Value of the Mean Spherical Candle-power or Lumens.

10. To facilitate the above calculations these constants may be applied to the construction of a slide rule as shown in Fig. 11. The slide of this rule is divided into sections proportional to the constants for the 15° subdivisions, as given above, the sum of which is equal to unity, and each section subdivided into 10, or a multiple of 10, equal parts.

The upper scale or candle-power scale is subdivided uniformly and has a length equal to the slide. The lower scale or lumen scale is graduated into sections 2π times those in the upper scale.

To determine the mean hemispherical candle-power or lumens is the question of one or two minutes. The zero of the slide is set at the zero of the other scales, the cross-hair on the rider is placed over the value of the candle-power in the vertical direction deduced to scale, in the 0° section. The zero of the 15° section is then placed under the cross-hair, the rider remaining fixed. The cross-hair is then moved, the slide remaining fixed, to the value of the candle-power in the 15° direction on the 15° section and the zero of the 30° section placed under the cross-hair. These manipulations are repeated for the 30°, 60°, 75° and 90° section. The mean hemispherical candle-power can be read off the upper scale and the hemispherical lumens read off the lower scale under the final position of the cross-hair. Another advantage of the rule is that the lumens may be read off the lower scale at any time during the procedure, but one should remember that the value covers the spherical area 7° 30′ beyond the designating angle.

11. The mean spherical candle-power of a source may also be found by multiplying the horizontal candle-power by the spherical reduction factor provided the mean spherical reduction factor for that type of lamp is known, and the lumens found by multiplying by 4π.

Thus

$$\phi = 4\pi f I_h,$$

where

$$\phi = \text{number of lumens,}$$
$$f = \text{spherical reduction factor,}$$
$$I_h = \text{horizontal candle-power.}$$

LECTURE II

12. Having become familiar with the various methods of obtaining the amount of light available for illuminating purposes we may now proceed with the several methods of performing illumination calculations. It is the common practice in this country to consider the intensity of illumination on a horizontal plane as the basis of comparison or computation. This plane, known as the "working plane," is where the luminous effect of the source is utilized. In stores this working plane would be considered as even with the tops of the counters or 42 inches from the floor. In offices and similar

interiors the plane would be that of the desk top or about 30 inches from the floor.

13. One of the first methods of determining the value and distribution of illumination is known as the "point-by-point" method. While reflection from walls and ceiling will in most cases make this method impractical for illumination calculations it will, however, be found very useful in determining the distribution of illumination from a luminous source with respect to uniformity or for comparison with other sources or for approximately determining the location of lamps for a desired distribution of light.

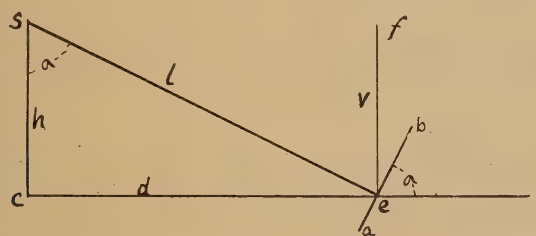

FIG. 12.—Illustration Explaining the Theory of the "Point-by-Point" Method.

These calculations involve trigonometric equations, but sets of constants may be derived and tabulated so that results may be calculated by simple arithmetic. If we assume the source of light to be located at a point S, Fig. 12, and let

I_a = candle-power a degrees from the vertical.
E_n = illumination on a normal surface.
E_h = illumination on a horizontal surface.
E_v = illumination on a vertical surface.
d = horizontal distance from vertical through lamp to point whose illumination it is desired to ascertain.
h = distance to lamp from horizontal plane.
l = distance direct from source to point considered.
a = the angle which the light rays make with the vertical.

Then the illumination intensity at a point on a normal plane ab will be.

$$E_n = \frac{I_a}{l^2} = \frac{I_a}{h^2+d^2} = I_a \frac{\cos^2 a}{h^2} \text{ foot-candles}$$

since $l = \frac{h}{\cos a}$ or $l^2 = \frac{h^2}{\cos^2 a}$.

The intensity of light on a horizontal plane ce making an angle a with this normal plane will be $E_h = \frac{I_a \cos a}{l^2}$, and by substituting as before

$$E_h = I_a \frac{\cos a}{l^2 a^3} = I_a \frac{\cos a}{h^2 + d^2} = I_a \frac{\cos}{h^2} \text{ foot-candles.}$$

The horizontal distance d from the vertical, may be found from the relation

$$d = h \tan a.$$

By the same reasoning the intensity of illumination on a vertical plane ef will be

$$E_v = I_a \frac{\sin a}{l^2} = I_a \frac{\sin a}{h^2 + d^2} = {}_a \frac{\sin^3 a}{d^2} \text{ foot-candles,}$$

since $l = \frac{d}{\sin a}$.

If it is desired to know the candle-power which will furnish a certain illumination the foregoing equations may be transposed, giving

$$I_a = E_n l^2 = E_n (h^2 + d^2) = E_n \frac{h^2}{\cos^2 a},$$

the candle-power required to illuminate a surface normal to the rays,

$$I_a = E_h \frac{l^2}{\cos a} = E_h \frac{h^2 + d^2}{\cos a} = E_h \frac{h^2}{\cos^3 a},$$

the candle-power necessary to give a horizontal illumination E_h, and

$$I_a = E_v \frac{l^2}{\sin a} = E_v \frac{(h^2 + d^2)}{\sin a} = E_v \frac{d^2}{\sin^3 a},$$

the candle-power sufficient to illuminate a vertical surface d feet from the source with an illumination of E_v foot-candles.

14. The values of cos a, tan a, $\cos^2$ a, $\sin^2$ a, $\cos^3$ a and $\sin^3$ a, from 0° to 90° are given in Table I, which will facilitate the use of the preceding equations.

Illumination on horizontal areas and the candle-power to produce that illumination are the most common calculations in the distribution of light. In street lighting and in interior lighting where the lamps are equipped with opaque reflectors which throw the light downward on floors or surfaces dark in color, these equations are applicable and will give very approximate results. A set of constants per unit candle-power for various heights of suspension of the

source above the plane of reference may be tabulated making preliminary determinations of such an installation comparatively simple. It will be seen that in the equation $E_h = I_a \frac{\cos^3 a}{h^2}$ the values of $\frac{\cos^3 a}{h^2}$ can be determined for various values of a and h, and designated by K, then $E_h = KI_a$ and $I_a = \frac{E_h}{K}$.

TABLE I

Cos a	Tan a	a	Cos²a	Cos³a		Cos a	Tan a	a	Cos²a	Cos³a	
1.00	.000	0	1.00	1.000	90	.694	1.04	46	.482	.335	44
.99985	.0175	1	.999	.999	89	.682	1.07	47	.465	.317	43
.9994	.0349	2	.998	.998	88	.669	1.11	48	.447	.299	42
.998	.0524	3	.997	.996	87	.656	1.15	49	.430	.282	41
.997	.0699	4	.995	.993	86	.643	1.19	40	.413	.265	40
.996	.0875	5	.992	.988	85	.629	1.23	51	.395	.249	39
.994	.105	6	.989	.983	84	.615	1.28	52	.379	.233	38
.992	.124	7	.985	.978	83	.602	1.33	53	.362	.218	37
.990	.140	8	.981	.971	82	.588	1.38	54	.345	.203	36
.988	.1598	9	.975	.963	81	.573	1.43	55	.329	.189	35
.985	.176	10	.970	.955	80	.559	1.48	56	.312	.175	34
.982	.194	11	.963	.946	79	.544	1.54	57	.296	.161	33
.978	.212	12	.957	.936	78	:529	1.60	58	.280	.149	32
.974	.230	13	.949	.925	77	.515	1.66	59	.265	.137	31
.970	.240	14	.941	.913	76	.500	1.73	60	.250	.125	30
.966	.268	15	.933	.901	75	.485	1.80	61	.235	.113	29
.961	.287	16	.924	.888	74	.469	1.88	62	.220	.103	28
.956	.306	17	.914	.874	73	.454	1.96	63	.206	.0936	27
.951	.325	18	.904	.860	72	.438	2.05	64	.192	.0843	26
.945	.344	19	.894	.845	71	.423	2.14	65	.178	.0755	25
.939	.364	20	.883	.830	70	.407	2.25	66	.165	.0673	24
.933	.384	21	.872	.814	69	.391	2.35	67	.152	.0596	23
.927	.404	22	.859	.797	68	.375	2.47	68	.140	.0526	22
.920	.424	23	.847	.780	67	.358	2.60	69	.128	.0460	21
.913	.445	24	.834	.762	66	.342	2.75	70	.117	.0400	20
.906	.466	25	.821	.744	65	.325	2.90	71	.106	.0345	19
.899	.488	26	.808	.725	64	.309	3.08	72	.0955	.0920	18
.891	.509	27	.794	.707	63	.292	3.27	73	.0855	.0250	17
.882	.532	28	.779	.688	62	.275	3.48	74	.0759	.0209	16
.874	.554	29	.764	.669	61	.259	3.73	75	.0670	.0173	15
.866	.577	39	.750	.659	60	.242	4.01	76	.0586	.0142	14
.857	.601	31	.735	.630	59	.225	4.33	77	.0506	.0114	13
.848	.625	32	.719	.610	59	.208	4.70	78	.0432	.00899	12
.838	.649	33	.703	.590	57	.191	5.14	79	.0363	.00686	11
.829	.675	34	.697	.570	56	.173	5.67	80	.0301	.00520	10
.819	.700	35	.671	.550	55	.156	6.31	81	.9244	.00379	9
.809	.726	36	.655	.529	54	.139	7.11	82	.0193	.00268	8
.798	.753	37	.637	.509	53	.122	9.14	83	.0148	.00181	7
.788	.781	38	.621	.489	52	.1045	9.51	84	.0109	.00115	6
.777	.810	39	.694	.469	51	.0872	11.43	85	.00760	.000661	5
.766	.839	40	.587	.449	50	.0697	14.3	86	.00486	.000339	4
.754	.869	41	.569	.430	49	.0523	19.08	87	.00374	.000144	3
.745	.900	42	.552	.410	48	.0349	28.64	88	.00122	.0000425	2
.731	.932	43	.534	.391	47	.0174	57.29	89	.000306	.0000053	1
.719	.966	44	.517	.372	46	.00	∞	90	.0000	.0000	0
.707	1.00	45	.500	.353	45						
Sin a			Sin²a	Sin³a	a	Sin a			Sin²a	Sin³a	a

15. In Table II the values of $\frac{\cos^3 a}{h^2} = K$ are tabulated for heights from 1.to 50 feet and for every 5° from 0° to 85° from the vertical. It will also be noticed that the values of the horizontal distance, d, are also given for each value of K.

TABLE II

h		0°	5°	10°	15°	20°	25°	30°	35°
1	d	.00	.09	.18	.27	.36	.47	.58	.70
	K	1.00	.989	.955	.901	.830	.744	.650	.550
2	d	.00	.18	.35	.54	.73	.93	1.15	1.40
	K	.25	.247	.239	.225	.207	.186	.162	.137
3	d	.00	.26	.53	.80	1.09	1.40	1.73	2.10
	K	.111	.110	.106	.100	.0922	.0827	.0722	.0611
4	d	.00	.35	.71	1.07	1.46	1.87	2.31	2.80
	K	.0625	.0618	.0597	.0563	.0519	.0465	.0406	.0344
5	d	.00	.44	.88	1.34	1.82	2.33	2.89	3.50
	K	.0400	.0395	.0382	.0361	.0332	.0298	.0260	.0220
6	d	.00	.53	1.06	1.61	2.18	2.80	3.46	4.20
	K	.0278	.0275	.0265	.0250	.0231	.0207	.0180	.0153
7	d	.00	.61	1.23	1.88	2.55	3.26	4.04	4.90
	K	.0204	.0202	.0195	.0184	.0169	.0152	.0133	.0112
8	d	.00	.70	1.41	2.14	2.91	3.73	4.62	5.60
	K	.0156	.0154	.0149	.0141	.0130	.0116	.0102	.00859
9	d	.00	.79	1.59	2.41	3.28	4.20	5.20	6.30
	K	.0123	.0122	.0118	.0111	.0102	.00919	.00802	.00679
10	d	.00	.88	1.76	2.68	3.64	4.66	5.77	7.00
	K	.0100	.00989	.00955	.00901	.00830	.00744	.00650	.00550
11	d	.00	.96	1.94	2.95	4.00	5.13	6.35	7.70
	K	.00826	.00817	.00789	.00745	.00686	.00615	.00537	.00454
12	d	.00	1.05	2.12	3.21	4.37	5.60	6.93	8.40
	K	.00694	.00686	.00663	.00626	.00576	.00517	.00451	.00382
13	d	.00	1.14	2.29	3.48	4.73	6.06	7.51	9.10
	K	.00592	.00585	.00565	.00533	.00491	.00440	.00384	.00325
14	d	.00	1.23	2.47	3.75	5.10	6.53	8.08	9.80
	K	.00510	.00504	.00487	.00460	.00423	.00380	.00331	.00280
15	d	.00	1.31	2.64	4.02	5.46	7.00	8.66	10.5
	K	.00444	.00439	.00425	.00400	.00369	.00331	.00289	.00244
16	d	.00	1.40	2.82	4.29	5.82	7.46	9.24	11.2
	K	.00391	.00386	.00373	.00352	.00324	.00291	.00254	.00215
17	d	.00	1.49	3.00	4.55	6.19	7.93	9.82	11.9
	K	.00346	.00342	.00331	.00312	.00287	.00258	.00225	.00190
18	d	.00	1.58	3.17	4.82	6.55	8.40	10.4	12.6
	K	.00309	.00305	.00295	.00278	.00256	.00230	.00201	.00170
19	d	.00	1.66	3.35	5.09	6.92	8.86	11.0	13.3
	K	.00277	.00274	.00265	.00250	.00230	.00206	.00180	.00152
20	d	.00	1.75	3.53	5.36	7.28	9.33	11.55	14.0
	K	.00250	.00247	.00239	.00225	.00207	.00186	.00162	.00137
21	d	.00	1.85	3.70	5.63	7.64	9.80	12.1	14.7
	K	.00227	.00224	.00217	.00204	.00188	.00169	.00147	.00125

TABLE II

5°	50°	55°	60°	65°	70°	75°	80°	85°
00	1.19 .266	1.43 .189	1.73 .125	2.14 .0755	2.75 .0400	3.73 .0173	5.67 .00524	11.4 .000661
00 4	2.38 .0664	2.80 .0472	3.46 .0313	4.29 .0189	5.50 .0100	7.46 .00433	11.34 .00131	22.8 .000165
00 3	3.58 .0295	4.28 .0210	5.20 .0139	6.43 .00839	8.24 .00445	11.20 .00193	17.0 .000582	34.3 .0000735
00 1	4.77 .0166	5.71 .0118	6.93 .00781	8.58 .00472	10.99 .00250	14.93 .00108	22.69 .000327	45.7 .0000413
00 1	5.96 .0106	7.14 .00755	8.66 .00500	10.72 .00302	13.74 .00160	18.66 .000694	28.36 .000209	57.2 .0000264
00 82	7.15 .00738	8.57 .00524	10.4 .00347	12.9 .00210	16.5 .00111	22.4 .000482	34.0 .000145	68.6 .0000184
00 22	8.34 .00542	10.0 .00385	12.1 .00255	15.0 .00154	19.2 .000817	26.1 .000354	39.7 .000107	80.1 .0000135
00 53	9.53 .00415	11.4 .00295	13.8 .00195	17.2 .00118	22.0 .000625	30.0 .000271	45.4 .0000818	91.5 .0000103
00 37	10.7 .00328	12.8 .00233	15.6 .00154	19.3 .000932	24.7 .000494	33.6 .000214	51.0 .0000646	103. .00000816
.0 54	11.9 .00266	14.3 .00189	17.3 .00125	21.5 .000755	27.5 .000400	37.3 .000173	56.7 .0000524	114. .00000661
.0 92	13.1 .00220	15.7 .00156	19.0 .00103	23.6 .000624	30.2 .000330	41.0 .000143	62.4 .0000433	126. .00000546
.0 46	14.3 .00184	17.1 .00131	20.8 .000868	25.7 .000524	33.0 .000278	44.8 .000120	68.0 .0000364	137. .00000459
.0 09	15.5 .00157	18.6 .00112	22.5 .000740	27.9 .000447	35.7 .000237	48.5 .000103	73.7 .0000310	149. .00000391
.0 80	16.7 .00136	20.0 .000963	24.2 .000638	30.0 .000385	38.5 .000204	52.2 .0000885	79.4 .0000267	160. .00000337
5.0 .57	17.9 .00112	21.4 .000839	26.0 .000556	32.2 .000336	41.2 .000178	56.0 .0000771	85.1 .0000233	171. .00000294
6.0 38	19.1 .00104	22.8 .000737	27.7 .000488	34.3 .000295	44.0 .000156	59.7 0000677	90.7 .0000205	183. .00000258
7.0 22	20.3 .000919	24.3 .000653	29.5 .000433	36.5 .000261	46.7 .000138	63.5 .0000600	96.4 .0000181	194. .00000194
8.0 09	21.5 .000820	25.7 .000583	31.2 .000386	38.6 .000233	49.5 .000124	67.2 .0000535	102. .0000162	206. .00000206
9.0 980	22.6 .000736	27.1 .000523	32.9 .000346	40.7 .000209	52.2 .000111	70.9 .0000480	108. .0000145	217. .00000183
.0 884	23.8 .000664	28.5 .000472	34.6 .000313	42.9 .000189	55.0 .000100	74.6 .0000433	113. .0000131	229. .00000229
1.0 802	25.1 .000602	30.0 .000428	36.4 .000284	45.0 .000171	57.7 .0000907	78.4 .0000393	119. .0000119	240. .00000150

TABLE II—Continued

h		0°	5°	10°	15°	20°	25°	30°	35°
22	d	.00	1.93	3.88	5.89	8.01	10.3	12.7	15.4
	K	.00207	.00204	.00197	.00186	.00171	.00154	.00134	.00114
23	d	.00	2.01	4.05	6.16	8.37	10.7	13.3	16.1
	K	.00189	.00187	.00181	.00170	.00157	.00141	.00123	.00104
24	d	.00	2.10	4.23	6.43	8.74	11.2	13.9	16.8
	K	.00174	.00172	.00166	.00156	.00144	.00129	.00113	.000954
25	d	.00	2.19	4.41	6.70	9.10	11.7	14.4	17.5
	K	.00160	.00158	.00153	.00144	.00133	.00119	.00104	.000879
26	d	.00	2.28	4.58	6.97	9.46	12.1	15.0	18.2
	K	.00148	.00146	.00141	.00133	.00123	.00110	.000961	.000813
27	d	.00	2.36	4.76	7.23	9.83	12.6	15.6	18.9
	K	.00137	.00136	.00131	.00124	.00114	.00102	.000891	.000754
28	d	.00	2.45	4.94	7.50	10.2	13.1	16.2	19.6
	K	.00128	.00126	.00122	.00115	.00106	.000950	.000829	.000701
29	d	.00	2.54	5.11	7.77	10.6	13.5	16.7	20.3
	K	.00119	.00118	.00114	.00107	.000987	.000885	.000772	.000654
30	d	.00	2.63	5.29	8.04	10.9	14.0	17.3	21.0
	K	.00111	.00110	.00106	.00100	.000922	.000827	.000722	.000611
32	d	.00	2.80	5.64	8.57	11.3	14.9	18.5	22.4
	K	.000976	.000964	.000932	.000880	.000811	.000726	.000633	.000537
34	d	.00	2.97	6.00	9.12	12.4	15.9	19.6	23.8
	K	.000866	.000855	.000826	.000780	.000718	.000644	.000561	.000476
35	d	.00	3.06	6.17	9.37	12.4	16.3	20.2	24.5
	K	.000816	.000806	.000779	.000736	.000677	.000606	.000530	.000449
36	d	.00	3.15	6.35	9.63	13.1	16.8	20.8	25.2
	K	.000772	.000762	.000737	.000695	.000640	.000574	.000500	.000424
38	d	.00	3.33	6.71	10.2	13.8	17.7	21.9	26.6
	K	.000692	.000684	.000661	.000624	.000575	.000515	.000449	.000381
40	d	.00	3.50	7.06	10.7	14.6	18.6	23.1	28.0
	K	.000625	.000617	.000597	.000562	.000518	.000465	.000405	.000344
42	d	.00	3.67	7.41	11.2	15.3	19.6	24.2	29.4
	K	.000567	.000560	.000541	.000511	.000470	.000421	.000368	.000312
44	d	.00	3.85	7.76	11.8	16.0	20.5	25.4	30.8
	K	.000516	.000510	.000493	.000465	.000429	.000384	.000335	.000284
45	d	.00	3.94	7.94	12.1	16.4	21.0	26.0	31.5
	K	.000493	.000487	.000471	.000445	.000410	.000367	.000320	.000272
46	d	.00	4.03	8.12	12.3	16.8	21.5	26.5	32.2
	K	.000473	.000467	.000451	.000425	.000392	.000352	.000306	.000260
48	d	.00	4.2	8.47	12.8	17.5	22.4	27.2	33.6
	K	.000434	.000428	.000414	.000391	.000361	.000323	.000282	.000239
50	d	.00	4.38	8.82	13.4	18.2	23.3	28.8	35.0
	K	.000400	.000395	.000382	.000360	.000332	.000297	.000260	.000220

TABLE II—Continued

50°	55°	60°	65°	70°	75°	80°	85°
26.2	31.4	38.1	47.2	60.5	82.1	125.	251.
.000549	.000390	.000258	.000156	.0000827	.0000358	.0000108	.00000137
27.4	32.8	39.8	49.3	63.2	85.8	130.	263.
.000502	.000357	.000236	.000143	.0000757	.0000328	.00000990	.00000125
28.6	34.3	41.6	51.5	65.9	89.6	136.	275.
.000461	.000328	.000217	.000131	.0000695	.0000301	.00000909	.00000115
29.8	35.7	43.3	53.6	68.7	93.3	142.	286.
.000425	.000302	.000200	.000121	.000064	.0000277	.00000838	.00000106
31.0	37.1	45.0	55.8	71.4	97.0	147.	297.
.000393	.000279	.000185	.000112	.0000592	.0000257	.00000775	.000000977
32.2	38.6	46.8	57.9	74.2	101.	153.	309.
.000364	.000259	.000172	.000104	.0000549	.0000238	.00000718	.000000907
33.4	40.0	48.5	60.0	76.9	105.	159.	320.
.000339	.000241	.000159	.0000963	.0000510	.0000221	.00000668	.000000844
34.5	41.4	50.2	62.2	79.7	108.2	164.5	332.
.000316	.000224	.000149	.0000898	.0000476	.0000206	.00000622	.000000786
35.7	42.8	52.0	64.3	82.4	112.	170.	343.
.000295	.000210	.000139	.0000839	.0000445	.0000193	.00000582	.000000735
38.1	45.6	55.4	68.6	88.0	119.	181.	366.
.000249	.000185	.000122	.0000737	.0000390	.0000169	.00000507	.000000645
40.5	48.5	58.8	73.0	93.5	127.	193.	389.
.000229	.000164	.000108	.0000653	.0000347	.0000150	.00000450	.000000571
41.8	50.0	60.6	75.0	96.3	131.	199.	400.
.000216	.000154	.000102	.0000616	.0000326	.0000141	.00000425	.000000540
42.9	51.4	62.3	77.2	99.0	134.	204.	412.
.000205	.000146	.0000965	.0000582	.0000309	.0000133	.00000401	.000000510
45.3	54.2	65.9	81.5	104.	142.	215.	435.
.000184	.000131	.0000866	.0000522	.0000277	.0000120	.00000360	.000000457
47.7	57.2	69.4	85.9	110.	149.	227.	457.
.000166	.000118	.0000781	.0000471	.0000250	.0000108	.00000325	.000000413
50.0	60.0	72.7	90.0	115.5	157.	238.	480.
.000150	.000107	.0000709	.0000428	.0000227	.00000981	.00000295	.000000375
52.5	62.8	76.3	94.5	121.	164.	250.	503.
.000137	.0000976	.0000645	.0000390	.0000207	.00000894	.00000269	.000000341
53.6	64.3	78.0	96.5	124.	168.	255.	515.
.000131	.0000933	.0000617	.0000373	.0000198	.00000854	.00000257	.000000326
54.9	65.7	79.8	98.8	126.	172.	261.	526.
.000125	.0000893	.0000591	.0000357	.0000189	.00000818	.00000246	.000000312
57.3	68.6	83.2	103.	132.	179.	272.	549.
.000115	.0000821	.0000543	.0000328	.0000174	.00000752	.00000226	.000000287
59.6	71.5	86.6	107.	137.	186.	284.	572.
.000106	.0000755	.0000500	.0000302	.0000160	.00000692	.00000208	.000000265

These tables can be extended by multiples of 10, the values of d being multiplied by 10 and the values of K divided by 100, as may be noted from the relations of the values of d and K for heights of 1 and 10 feet.

To make clear the manipulation of these tables we will find the illumination on a horizontal surface 10 feet below a luminous source and at a point where the light rays make an angle of 60° with the vertical. From the tables it will be seen that for 10 feet in height and 60° from the vertical, K=.00125 and d=17.3. If the candle-power of the source at 60° from the vertical is 200 candle-power then the horizontal illumination at a point 17.3 feet from a vertical through the lamp will be

$$200 \times .00125 = 0.25 \text{ foot-candles.}$$

The candle-power of the source in that direction necessary to give an illumination of 0.25 foot-candles at that point will be

$$0.25/.00125 = 200 \text{ candle-power.}$$

When, as is often the case in interior lighting, it is desirable to obtain the values of illumination at definite distances along the horizontal, tables like the second set (Table III) will be found more convenient. These tables gives values of $K = \frac{\cos^3 a}{h^2}$ and a (degrees from the vertical) for various heights and horizontal distances. The constants in these tables are used in the same manner as illustrated in the foregoing problem.

TABLE III

h	d	0′	2′	4′	6′	8′	10′	12′	14′	16′
1	a	00°	63° 25′	75° 55′	80° 30′	82° 50′	84° 20′	85° 15′	85° 55′	68° 25′
	K	1.00	.893	.0144	.00441	.00190	.000961	.000567	.000361	.000244
2	a	00°	45° 0′	63° 25′	71° 35′	76° 0′	78° 40′	80° 35′	81° 50′	82° 55′
	K	.250	.0883	.0224	.0079	.00355	.00191	.00111	.000722	.000473
3	a	00°	33° 40′	53° 5′	63° 25′	69° 25′	73° 20′	75° 55′	77° 55′	79° 25′
	K	.111	.0640	.0241	.00992	.00480	.00262	.00159	.00102	.000693
4	a	00°	26° 35′	45° 0′	56° 20′	63° 25′	68° 10′	71° 35′	74° 5′	76° 0′
	K	.0625	.0447	.0221	.0106	.00560	.00322	.00197	.00144	.000887
5	a	00°	21° 50′	38° 40′	50° 10′	58° 0′	63° 25′	67° 20′	70° 20′	72° 40′
	K	.0400	.0320	.0191	.0105	.00596	.00357	.00228	.00152	.00106
6	a	00°	18° 25′	33° 40′	45° 0′	53° 5′	59° 0′	63° 25′	66° 50′	69° 25′
	K	.0278	.0236	.0160	.00982	.00602	.00380	.00248	.00169	.00121
7	a	00°	15° 55′	29° 45′	40° 35′	48° 50′	55° 0′	59° 45′	63° 25′	66° 20′
	K	.0204	.0182	.0134	.00892	.00583	.00385	.00261	.00182	.00131
8	a	00°	14° 0′	26° 35′	36° 50′	45° 0′	51° 20′	56° 20′	60° 15′	63° 25′
	K	.0156	.0143	.0112	.00801	.00552	.00382	.00266	.00191	.00140
9	a	00°	12° 30′	24° 0′	33° 40′	41° 40′	48° 0′	53° 5′	57° 15′	60° 40′
	K	.0123	.0115	.00941	.00711	.00515	.00369	.00268	.00195	.00146
10	a	00°	11° 20′	21° 50′	31° 0′	38° 40′	45° 0′	50° 10′	54° 30′	58° 0′
	K	.0100	.00942	.00800	.00630	.00476	.00353	.00262	.00196	.00149

h	d	0′	4′	8′	12′	16′	20′	24′	28′	32′
11	a	00°	20° 0′	36° 0′	47° 30′	55° 30′	61° 10′	65° 25′	68° 35′	71° 0′
	K	.00826	.00685	.00441	.00254	.00150	.000925	.000597	.000407	.000284
12	a	00°	18° 25′	33° 40′	45° 0′	53° 5′	59° 0′	63° 25′	66° 50′	69° 25′
	K	.00694	.00592	.00400	.00245	.00151	.000950	.000620	.000425	.000300
13	a	00°	17° 5′	31° 35′	42° 40′	50° 55′	56° 55′	61° 35′	65° 5′	67° 55′
	K	.00592	.00517	.00366	.00235	.00148	.000965	.000640	.000440	.000316
14	a	00°	16° 0′	29° 45′	40° 40′	48° 50′	55° 0′	59° 45′	63° 25′	66° 20′
	K	.00510	.00453	.00333	.00222	.00145	.000965	.000653	.000455	.000329
15	a	00°	14° 55′	28° 5′	38° 40′	46° 50′	53° 5′	58° 0′	61° 50′	64° 55′
	K	.00444	.00401	.00305	.00212	.00142	.000964	.000661	.000469	.000340
16	a	00°	14° 0′	26° 35′	36° 50′	45° 0′	51° 20′	56° 20′	60° 15′	63° 25′
	K	.00391	.00357	.00279	.00200	.00138	.000954	.000668	.000476	.000349
17	a	00°	13° 15′	25° 10′	35° 15′	43° 15′	49° 40′	54° 40′	58° 45′	62° 0′
	K	.00346	.00319	.00256	.00189	.00134	.000937	.000668	.000485	.000358
18	a	00°	12° 30′	24° 0′	33° 40′	41° 40′	48° 0′	53° 10′	57° 15′	60° 40′
	K	.00309	.00287	.00235	.00178	.00129	.000927	.000667	.000488	.000364
19	a	00°	11° 55′	22° 50′	32° 20′	40° 5′	46° 25′	51° 40′	55° 50′	59° 20′
	K	.00277	.00260	.00217	.00167	.00124	.000906	.000662	.000490	.000368
20	a	00°	11° 20′	21° 50′	31° 0′	38° 40′	45° 0′	50° 10′	54° 30′	58° 0′
	K	.0025	.00235	.00200	.00157	.00119	.000883	.000655	.000490	.000373

h	d	0′	8′	16′	24′	32′	40′	48′	56′	64′
21	a	00°	20° 50′	37° 20′	48° 50′	56° 45′	62° 20′	66° 20′	59° 25′	71° 50′
	K	.00227	.00185	.00114	.000646	.000374	.0000629	.0000279	.0000138	.00000743
22	a	00°	20° 0′	36° 5′	47° 30′	55° 30′	61° 10′	65° 20′	68° 35′	71° 0′
	K	.00206	.00171	.00109	.000637	.000376	.0000699	.0000314	.0000158	.00000840
23	a	00°	19° 10′	34° 45′	46° 10′	54° 15′	60° 51′	64° 25′	67° 40′	70° 10′
	K	.00189	.00159	.00105	.000628	.000378	.0000776	.0000350	.0000174	.00000944
24	a	00°	18° 25′	33° 40′	45° 0′	53° 10′	59° 0′	63° 25′	66° 45′	69° 25′
	K	.00174	.00148	.00100	.000614	.000375	.0000854	.0000387	.0000195	.00001055
25	a	00°	17° 35′	32° 40′	43° 50′	52° 0′	58° 0′	62° 30′	65° 55′	68° 40′
	K	.00160	.00138	.000955	.000600	.000373	.0000930	.0000429	.0000216	.00001175
26	a	00°	17° 5′	31° 35′	42° 40′	50° 55′	56° 55′	61° 35′	65° 5′	67° 50′
	K	.00148	.00129	.000915	.000587	.000371	.000101	.0000470	.0000238	.0000130
27	a	00°	16° 30′	30° 40′	41° 40′	49° 50′	55° 55′	60° 40′	64° 15′	67° 5′
	K	.00137	.00121	.000874	.000573	.000369	.000110	.0000510	.0000261	.0000144
28	a	00°	16° 0′	29° 45′	40° 35′	48° 50′	55° 0′	59° 45′	63° 25′	66° 20′
	K	.00128	.00113	.000834	.000558	.000364	.000118	.0000556	.0000285	.0000157
29	a	00°	15° 25′	28° 55′	39° 35′	47° 50′	54° 0′	58° 50′	62° 35′	65° 35′
	K	.00119	.00106	.000798	.000545	.000360	.000126	.0000600	.0000310	.0000172
30	a	00°	14° 55′	28° 5′	38° 40′	46° 50′	53° 10′	58° 0′	61° 50′	64° 50′
	K	.00111	.00100	.000765	.000530	.000355	.000135	.0000645	.0000336	.0000187

17. The results calculated according to the foregoing discussion may be represented graphically in several ways. One common method is to plot curves as shown in Fig. 13. The foot-candle intensity is laid off as ordinates and the distances from the vertical plotted as abscissæ. These curves represent the horizontal intensity on a working plane eight feet below a 100-watt tungsten lamp equipped with extensive, intensive and focusing types of reflectors.

A very satisfactory method of representing the intensity of illumination over certain areas is to lay off the illuminated surface to

some convenient scale and calculate and plot equiluminous lines. Such a diagram is shown in Fig. 14 which illustrates the distribution of illumination from four sources, of rather strong downward intensity, placed over the areas receiving the greatest illumination. The vertical distribution of light through the center of the surface is represented by the broken line at the side of the diagram.

18. The ordinary slide rule (8) may be used for calculating illumination intensities and will be found convenient when tables

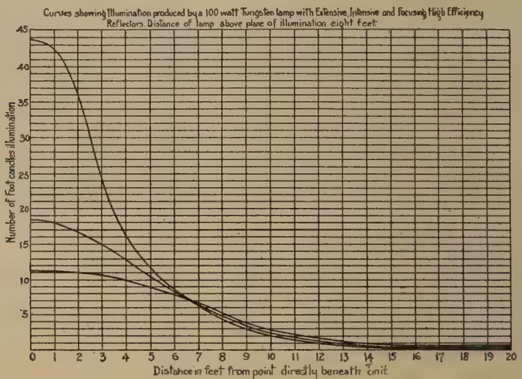

FIG. 13.—Representation of Illumination Intensity.

or diagrams are not available. If the normal or horizontal illumination is required the formulæ

$$E_n = \frac{I_a \cos^2 a}{h^2}$$

and

$$E_h = \frac{I_a \cos^3 a}{h^2}$$

are used respectively. It is evident that after the values of $\cos^2 a$ and $\cos^3 a$ are obtained, the calculations can be performed by the ordinary processes of multiplication and division. The determination of a, $\cos^2 a$, and $\cos^3 a$ are quite simple if the height of the lamp h and the horizontal distance d are known. This deduction can perhaps be best understood from an example. Suppose

$$h = 9.5 \text{ and } d = 7, \text{ then } d/h = \tan a.$$

From this we can obtain a from the slide rule by the use of the "T" tangent scale on the back of the slide. In the case above, place the right-hand index of the tangent scale over 9.5 and find over 7 the angle a equal to 36° 20′. To determine the value of cos a we resort

to the "S" sine scale since $\cos a = \sin(90 - a)$. Then $90 - a = 53° 40'$. Set the slide so that the indices of slide and stock correspond and read over 53° 40′ on the "S" scale, the cosine of 36° 20′ equal to 0.805. Set the runner over this value of cos a transferred to the lower scale and find the value of $\cos^2 a$ under the runner on the upper scale. To find the value of $\cos^3 a$ turn over the slide and multiply the value of $\cos^2 a$ obtained above by the value of cos a. If h is greater than d or if $h=7$ and $d=9.5$ we set the "T" scale as before with the index on the larger number but we will find over 7 not the value of a, but the value of the compliment of a or $(90° - a)$. Having found a the value of cos a can be found by means of the sine scale. The remainder of the process is the same as before.

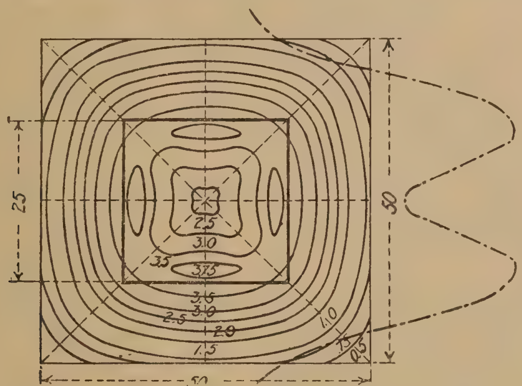

FIG. 14.—Representation of Illumination Intensity.

When the first digit of the greater number is less than the first digit of the smaller number, the left-hand index of the "T" scale should be set over the greater numbers. Thus if $H=12$ and $d=8$, place left-hand index of "T" scale over 12 and read over 8 the angle a, 53° 40′. The remaining calculations are performed as before.

19. The "calculator" is the name applied to an instrument designed by Norman Macbeth. It involves the principles of the slide-rule, by which the solution of many of the various mathematical problems which occur in illuminating engineering may be accomplished.

The calculator consists of two concentric revolvable discs having circular scales printed upon them, and a runner of transparent celluloid also turning about the center and having on its surface a fine radial line.

The computations which can be performed by this instrument are based on equations

$$E_n = \frac{I_a}{l^2} \text{ and } E_h = \frac{I_a \cos^3 a}{h^2},$$

which have already been discussed. Any of the desired values in these equations may be obtained by use of the calculator if the others are known. The calculator may also be used for ordinary multiplication and division.

The arrangement of the several scales upon the two discs is shown in Fig. 15. The large disc carries two scales; the scale on the outer

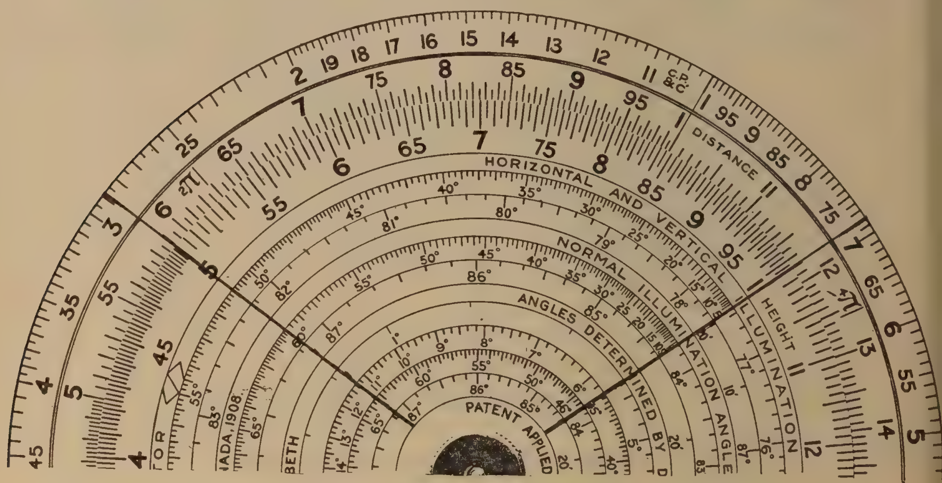

FIG. 15.—Macbeth's Calculator.

circle is used for reading both intensity of light in candle-power, and intensity of illumination in foot-candles. The inner scale is used to determine the distance d from the foot of the perpendicular drawn through the light source.

The smaller disc carries nine circular scales, beginning with the outer scale marked "height" gives the heights of the light sources above the given plane. The next two circles form a single scale which is marked "horizontal and vertical illumination angles" and is used in problems in which it is required to determine either the horizontal or vertical intensity of illumination from rays striking at a given angle, or for determining the angle of the incident rays when the height of the light source and the distance to the point from the vertical, are given.

The next two circles toward the center form a single scale marked "normal illumination angles" which is used in problems requiring determination of the intensity of normal illumination when the candle-power and angle are given, or when the intensity of illumination and height are given to read candle-power at all angles.

The remaining four circles constitute a single scale for determining the angle when the height and distance are given, or the distance corresponding to any given height when the angle is given.

The two settings illustrated in Fig. 15 show the method of obtaining the normal illumination intensity. In this case a 16 candle-

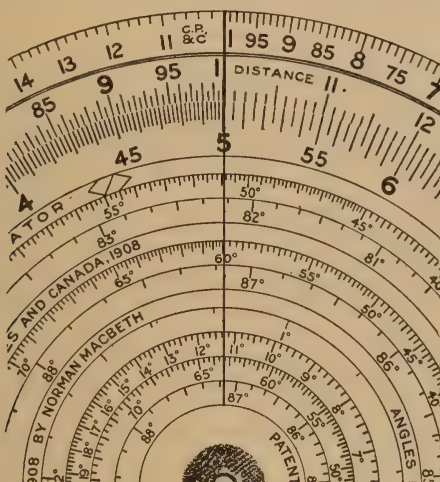

Fig. 16.—Macbeth's Calculator.

power lamp having a vertical downward candle-power of 7.2 and placed 5 feet above the plane. The runner is placed over 7.2 and zero on the small disc brought under the hair line. The runner is then moved to 5 on the height scale and the resultant intensity of illumination .288 is read off under the line on the outer scale. As in using a slide rule the position of the decimal point must be determined.

To determine the horizontal illumination at a point at some location, say 10 feet from a position directly under the lamp, it first becomes necessary to know the angle on the polar curve at which to read the candle-power of the source in this direction. To obtain this set 5 on the H scale over 10 on the D scale, Fig. 16, bring the runner to 1 on the D scale and under the runner in the second

smaller circle P scale, read 63° 20′. Assume the candle-power at this angle to be 15. Set the runner at 15 on the candle-power scale, Fig. 17, turn the inner disc to bring 63° 20′ on the scale marked "horizontal and vertical illumination angles" under the line. Hold the two discs, and bring the runner to 5 on the height scale. Under the runner on the outer scale read 542. To determine the position of the decimal point with both discs set, refer back to zero angle, from which we note that the equivalent candle-power at 0° 20′ is 1.35. The decimal point may then be readily determined by I/h^2 or 1.35/25, which equals 0.05 roughly, indicating that the previous reading should be .0540.

FIG. 17.—Macbeth's Calculator.

To determine the lumens, set 1 on the H scale on 4π on the D scale, bring the runner to the value of the mean spherical candle-power on the H scale and read under the runner on the D scale the value of the lumens.

There are several other calculations which may be performed by means of this ingenious little device and a set of conversion tables on the back of the calculator will be found very convenient for reference.

20. The flux of light method of performing illumination calculations forms the basis of a convenient method of determining ap-

proximately the number of lamps necessary for an installation. It consists in calculating the flux of light in lumens available for illuminating purposes and the amount of flux on the working plane necessary to give the desired illumination and equating the two results. We have already learned that the total lumens derived from a lamp is $4\pi I_{ms}$, where I_{ms} is the mean spherical intensity. Assume, that, due to the type of reflector, absorption and redirection of the rays, etc., that only a part k of the light reaches the working plane. Then we will have from one lamp $4\pi kI_{ms}$ lumens available for illuminating purposes. To illuminate an area of S square feet with an average intensity of E_o foot-candles will require SE_o lumens.

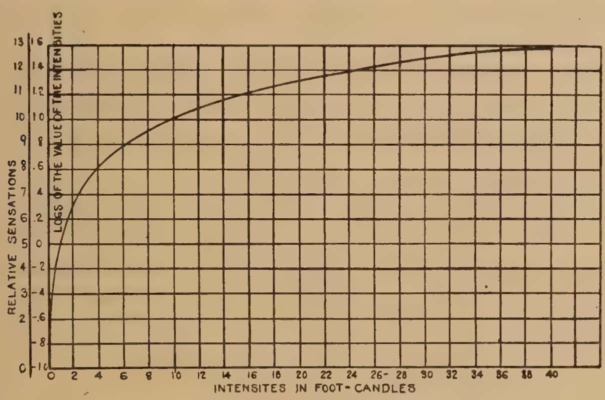

FIG. 18.—Relation of Sensations to Stimuli.

21. Thus the number of lamps required will be

$$N=\frac{SE_o}{4\pi kI_{ms}}=\frac{SE_o}{K'I_{ms}}.$$

By similar reasoning the area illuminated to an average intensity of E_o foot-candles by one lamp will be

$$s=\frac{4\pi kI_{ms}}{E_o}=\frac{K'I_{ms}}{E_o}.$$

In order to employ the flux of light method for practical calculations it becomes necessary to know the values of E_c for different classes of service.

In determining this intensity of illumination E_o for a certain interior it is extremely important that one possesses a clear conception of Fechner's law of vision. Briefly this law states that the sensations produced by the optical nerves vary approximately as the logarithm of the values of the stimuli producing those sensations.

This law is presented graphically by Fig. 18 (12), which is plotted with intensities in foot-candles as abscissæ, and the values of the logarithms of these intensities as ordinates. Referring to this curve it will be seen that the same percentage change in intensity will produce the same change in sensation. Thus by increasing the intensity from 2 to 4 foot-candles the same change in sensation will be effected as if the intensity were increased from four to eight, or from 20 to 40 foot-candles, the percentage increase being the same in all cases.

A study of this law will reveal the reason for the statement often seen in the technical press, that the effects produced by the use of additional lamps did not warrant the additional expenditure of energy. Thus it will be seen that every man who pretends to handle illumination problems with engineering intelligence should possess a practical knowledge of this fundamental law and install a number of lamps sufficient only to enable the details of the subjects illuminated to be clearly and easily perceived.

If we have given the values of the illumination intensity for a particular class of service and the effective lumens per watt of the equipment chosen, the determination of the number of lamps for a particular class of lighting becomes a simple matter.

Thus in the preceding expression $N=\frac{SE_o}{4\pi k I_{ms}}$,

$$4\pi k I_{ms}=WK$$

where W = watts or cubic foot of gas per hour per lamp and K = the effective lumens per watt or per cubic foot of gas per hour. Thus

$$N=\frac{SE_o}{WK},$$

S being the area in square feet, E_o, the average foot-candle intensity or lumens per square foot, and N the number of lamps. As an example of such a calculation, find the number of lamps necessary to illuminate a store 30 by 60 feet, or an area of 1800 square feet, with an intensity of 3.75 foot-candles.

If the walls and ceilings are assumed to be light in color, then with 100-watt tungsten lamps and clear prismatic reflectors there should be obtained 4.5 lumens per watt. Thus by substitution we have

$$N=\frac{SE_o}{WK}=\frac{1800\times 3.75}{100\times 4.5}=15 \text{ 100-watt lamps.}$$

Another method of arriving at the same result is to calculate the watts per square foot or cubic feet of gas per hour per square foot, and determine the number of lamps by dividing the total watts or cubic feet of gas required for the installation by the amounts taken by one lamp. Thus the

$$\text{watts per sq. ft., or cu. ft. per hour per sq. ft.} = \frac{\text{intensity in foot-candles or effective lumens per square foot.}}{\text{effective lumens per watt or per cu. ft. per hour from the luminous source.}}$$

$$\text{or } w = \frac{E_o}{K}.$$

In this way the solution of the preceding problem is:

$$w = \frac{E_o}{K} = \frac{3.75}{4.5} = 0.833 \text{ watts per square foot.}$$

The number of lamps will obviously be equal to the product of the area and the watts per square foot divided by the watts per lamp, or

$$N = \frac{\text{area} \times \text{watts per sq. ft.}}{\text{W per lamp}}.$$

By using 100-watt lamps and substituting we will get as before

$$N = \frac{1800 \times 0.833}{100} = 15 \text{ 100-watt lamps.}$$

By similar reasoning it will be found that 25 60-watt or 10 150-watt tungsten lamps will meet the requirements.

22. Having found the number of lamps it next becomes necessary to determine their location. One method of doing this is to divide the room into a number of equal areas and place an outlet over the center of each area. If the area is of such dimensions that it can be divided into n number of equal squares and a lamp placed at the center of each square, then the distance d between lamps will be

$$d = \sqrt{\frac{S}{n}}.$$

If the area be divided into n equal rectangles and a lamp placed at the center of each rectangle whose dimensions are b and c, then $b = \frac{S}{cN}$, the distance in one direction, and $c = \frac{S}{bN}$, the distance in the other direction. With 25 60-watt lamps we would have 72 square feet per lamp; with 15 100-watt lamps, 120 square feet per

lamp, etc. Thus with 100-watt lamps the best arrangement will be as shown in Fig. 19, where the room is divided into sections 10 by 12 feet, and one lamp placed over the center of each section.

23. The absorption of light method (18) of performing illumination calculations as suggested and developed fundamentally by Dr. McAllister promises possibilities as a means of solving some of the intricate problems of illumination. The theory of this method is that the lighting units within a room must produce the sum of the lumens absorbed by the various surfaces. From this relation one can readily determine the total lumens which must emanate from the luminous source to produce a certain incident illumination, since for a given surface there is a direct ratio between the number of lumens absorbed and the number of lumens reflected. From the

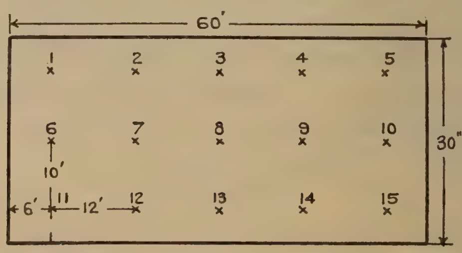

FIG. 19.—Arrangement of Lamps.

foregoing, it will be seen that the lumens absorbed by a surface is equal to the product of the incident illumination, the coefficient of absorption, and the area of the surface, or

$$\phi = aE_oS$$

where ϕ is the lumens absorbed, a the light absorption coefficient, E_o the average foot-candle intensity and S the areas illuminated.

The application of this method may be more clearly shown by means of an example.

24. Assume a room 15 feet in width, 20 feet in length, and 10 feet in height, having a white ceiling, light walls and a dark floor to be so lighted that we have an average illumination intensity of 2 foot-candles on the ceiling, 1 foot-candle on the walls and 4 foot-candles upon the floor. Assume also that the light absorption coefficient of the ceiling is 0.20, of the walls 0.40, and of the floor 0.90, and determine the candle-power necessary to produce the desired results.

Then by means of the above formula the lumens absorbed by the various surfaces will be

$$.20 \times 2 \times 300 = 120 \text{ for the ceiling.}$$
$$.40 \times 1 \times 700 = 280 \text{ for the walls.}$$
$$.90 \times 4 \times 300 = 1080 \text{ for the floor.}$$

This gives a total of 1480 lumens which would require a luminous source of 235 mean spherical candle-power.

It will be interesting to note in the above example that while only 1480 lumens are generated the total effective lumens on the various surfaces due to reflection and counter-reflection will be

$$2 \times 300 = 600 \text{ for the ceiling.}$$
$$1 \times 700 = 700 \text{ for the walls.}$$
$$4 \times 300 = 1200 \text{ for the floor.}$$

Or 2500 effective lumens.

If we assume that the light received by the walls from the ceiling and floor is equal to that reflected from the walls to the ceiling and floor and the amount absorbed by the walls supplied entirely by the source, then by means of the flux of light method one may very easily calculate the amounts of light which must be directed toward the floor and ceiling in order to give the desired intensities on these two surfaces. In the above example the total lumens effective at the ceiling is 600. Of these 120 lumens are absorbed and 480 lumens are reflected to the floor. Of the total incident illumination of 1200 lumens on the floor 1080 lumens are absorbed and 120 lumens reflected. Of the 600 lumens at the ceiling 120 come from the floor, leaving 480 to be supplied by the illuminants. Similarly of the 1200 lumens at the floor, 480 comes from the ceiling, leaving 720 lumens to be supplied by the lamps. Thus we have

	Area sq. ft.	Intensity.	Effective or incident lumens.	Co-efficient of absorption.	Lumens absorbed.
Ceiling	300	2	600	.20	120
Walls	700	1	700	.40	280
Floor	300	4	1200	.90	1080
			2500		1480

	Lumens reflected.	Lumens received by reflection.	Lumens supplied by lamps.
Ceiling	480	120	480
Walls	428	420*	280*
Floor	120	480	720
		1020	1480

* Assumed.

The discussion, thus far, on calculations, has dwelled on the determinations of illumination intensities due to the luminous source.

It is often desirable to know the distribution of light from a luminous source which will give an approximately uniform illumination.

25. In order to obtain uniform illumination from one lamp recourse is made to the expression $E_h = \frac{I_a}{h^2} \times \cos^3 a$, which is transposed into the form $I_a = \frac{E_h h^2}{\cos^3 a}$ where E_h is the horizontal illumination in foot-candles, a the angle which the luminous rays make

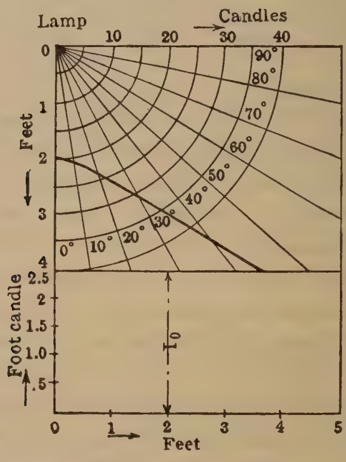

FIG. 20.—Polar Distribution Curve for Uniform Illumination (One Lamp).

with a vertical through the source; I_a the candle-power of the source of light a degrees from the vertical; and h the height of the lamp above the working plane.

For uniform illumination E_h and h^2 will be constant and I_a at various values of a must vary inversely as $\cos^3 a$. A polar curve (24) showing this relation is given in Fig. 20, which represents the distribution of intensity of a lamp in a vertical plane which would uniformly illuminate the area beneath it. Obviously, the area thus illuminated by one lamp is limited. In order, therefore, to uniformly illuminate larger areas a number of lamps must be employed and so arranged and with polar curves of such shape, as to produce the desired effect. In an interesting article by Mr. Wohlauer (24)

problems of this nature were discussed and polar curves derived showing various ways of obtaining uniform illumination. To simplify matters we will consider first the space beneath and between two lamps A and B and study the distribution of light in a vertical plane through the centers of the lamp.

26. The simplest way of effecting this is indicated by Fig. 21. There the vertical candle-power of each lamp is of sufficient value to give the desired intensity E_o beneath the source, and which decreases in a straight line to zero beneath the other lamp.

If we let d = distance between lamps,

d′ = distance from the lamp to point in question,

h = height of lamp,

E_o = desired illumination,

a = angle of ray with vertical,

I_a = candle-power a degrees with vertical,

then it may be shown that the intensity at d′ due to the source,

since $\frac{E_o}{E_d} = \frac{d}{d-d'}$ and $d = h \tan a$, is

$$E_d = \frac{E_o}{d'}(d' - h \tan a) = \frac{I_a \cos^3 a}{h^2},$$

therefore, the equation for this curve is

$$I_a = \frac{E_o H^2}{\cos^3 a}\left(\frac{d' - h \tan a}{d'}\right).$$

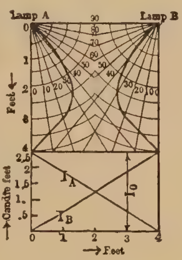

FIG. 21.—Polar Curves for Uniform Illumination (Two Lamps).

This is the simplest form of curve for uniform illumination with a number of lamps. It is evident, however, that with four lamps placed at the corners of a square the illumination along the sides of the square will be uniform, but not so at the intersection of the diagonals of the square. The illumination at this point is four times the intensity at a distance equal to $0.5\sqrt{2d^2}$ from a point beneath one lamp, or 1.17 I_o. In this figure it may be seen that the ratio

$$d/h = 1.$$

It often happens that it is impractical to locate lamps according to this relation. If the ceilings happen to be low and the illuminants of high candle-power the lamps must be placed further apart.

Under these conditions the polar curve must be made up of a combination of those shown in Figs. 20 and 21, i. e., each lamp must uniformly illuminate a section of the area beneath itself from which the illumination may then assume a constant decline reaching zero value where the uniform illumination due to the next lamp

begins. The curves of this nature are shown in Fig. 22. Another form of polar curve for uniform illumination is shown in Fig. 23. The equations of these curves are too complicated for practical purposes.

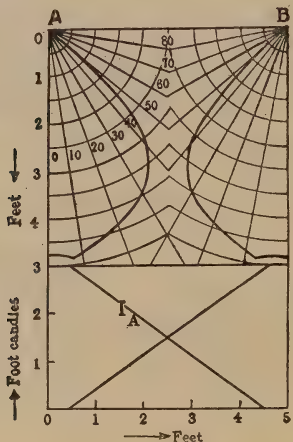

FIG. 22.

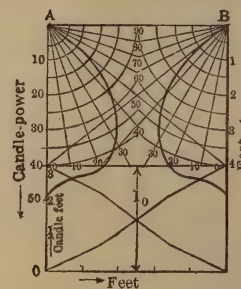

FIG. 23.

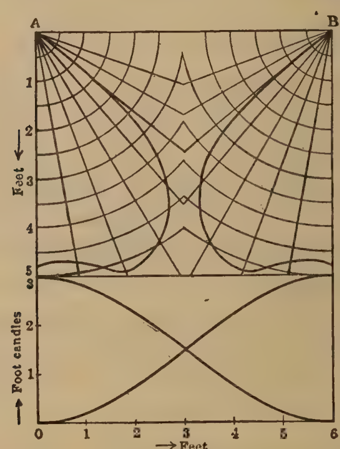

FIG. 24.

FIGS. 22, 23 and 24.—Polar Curves for Uniform Illumination, Two Lamps.

27. The general case of polar curves (24) yielding uniform illumination is indicated by Fig. 24. The equation for curves of this nature is

$$I_d = I_o\left(\frac{d - h\tan a}{d} + c\sin\frac{4\pi h\tan a}{d}\right),$$

where c is a constant which must be determined for each particular case.

28. In practice the uniformity of illumination can be obtained by choosing lamps and reflectors which direct the light in the desired manner. Many reflectors have been designed to distribute the light so as to accomplish this purpose. In Fig. 25 is shown the distribu-

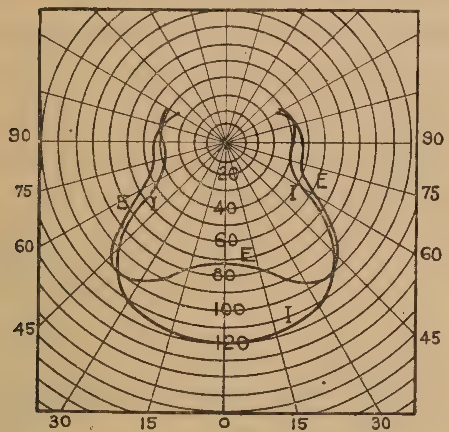

FIG. 25.—Polar Curves, I and E Types of Reflectors.

tion of light in a vertical plane around a 100-watt tungsten lamp when equipped with an extensive type and an intensive type of prismatic reflector. These curves show the candle-power in radial directions only and give no indication of the distribution of illum-

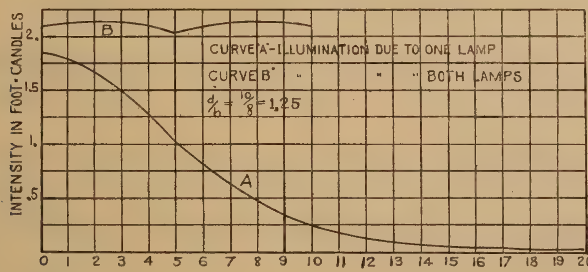

FIG. 26.—Illumination Curves I Type Reflector.

ination. This distribution on a horizontal plane may be calculated from these curves by use of the equation

$$E_h = \frac{I_a \cos^3 a}{h^2}.$$

The results of such calculations from the curves shown in Fig. 25 are shown in Figs. 26 and 27 (12).

Curve A, Fig. 26, shows the distribution of illumination on a horizontal plane due to one lamp placed 8 feet above the plane and equipped with an intensive reflector.

The ordinates are in foot-candles and the abscissas indicate distances from a point directly beneath the lamp. The illumination is far from uniform. However, if two lamps are placed at the same height and 10 feet apart, the illumination on the plane between points beneath the two will be nearly uniform as indicated by curve B, Fig. 26. It will be seen that the ratio of the distance between lamps to their height above the reference plane is 10 to 8, or 1.25 to 1. Thus, if this ratio is maintained when the lamps are suspended at other heights, the relative distribution of illumination will remain the same, although the intensity will be somewhat less. Similar curves for lamps with the extensive type of reflector

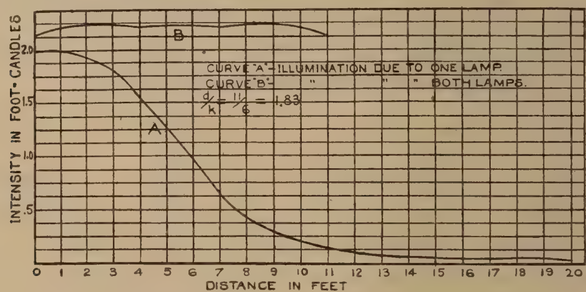

FIG. 27.—Illumination Curves E Type Reflector.

are shown in Fig. 27. Here the height is six feet, and the distance between lamps is 11 feet. In this case the value of d/h = 11/8 = 1.83.

Since the general distribution of light from lamps of other types and of other sizes is similar to these when equipped with the same type of reflector it will be seen that the constants 1.25 and 1.83 given above refer to the type of reflector, and may be applied to installations employing any of the commercial types of lamps, when equipped with these types of reflectors.

The relation of the distance between lamps to the height above the working plane d/h is of importance and deserves consideration. The area which can be uniformly illuminated is limited in practice.

This area, of course, depends upon the height of the lamps, but this, in turn, changes the intensity of illumination in the case of two or four lamps, as in the examples just cited.

29. In Fig. 28 are shown four theoretical curves (24) for uniform illumination having values of K=d/h=0.5, 1.0, 1.5, and 2.0. In this case the height and illumination are the same. It will be seen that the ratio of d/h=2.0 is as great as is practical, and that in most cases this relation will be much less. This expression d/h gives the minimum height h at which the lamps must be placed when located d distance apart. It can be shown that the same units equally spaced can be raised above the minimum height without impairing the uniformity of illumination, while a suspension lower than the minimum will result in non-uniform illumination. For one lamp it is evident that the illumination will be uniform beneath

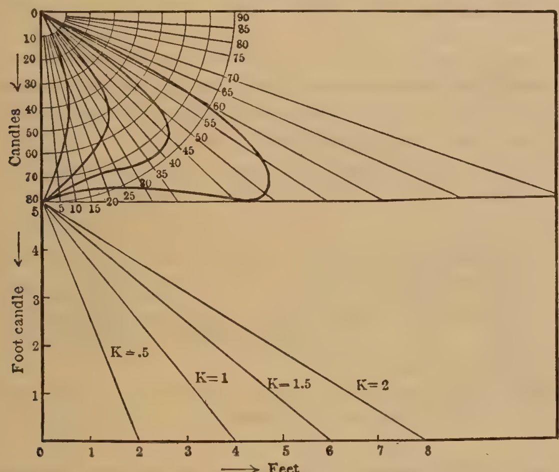

FIG. 28.—Polar Curves for Uniform Illumination for Different Ratios of Height and Distance.

it regardless of the height, provided the distribution of light is favorable, and that the intensity will vary inversely as the height, as shown by the curve RST, Fig. 29 (26).

If two lamps are considered the conditions existing will be as shown on the right of Fig. 29. For uniform illumination along a line connecting points beneath the lamps the minimum height is 4 feet, as shown in the right of the figure. At a height of 2 feet the illumination reaches zero between the two lamps, while for heights greater than 4 feet the uniformity is unimpaired, but the intensity becomes less. The change in intensity beneath the lamps for different heights is shown by the curve RSU, while the intensity midway beneath the two is indicated by VSU.

With two or four lamps the intensity of illumination beneath them ceases to vary inversely as the square of the height, or distance to the surface illuminated, since the light flux reaching the surface changes only by the change in amount which passes outside its boundary. In large interiors with a number of lamps which throw the light in a downward direction the intensity of illumination on the floor or working plane will vary slightly with different heights of suspension of the lamps; since all of the light from the lamps centrally located will strike the floor no matter what the height and the difference in the total flux is due only to that amount which strikes the walls from those lamps around the outer edges, part of which will be reflected back.

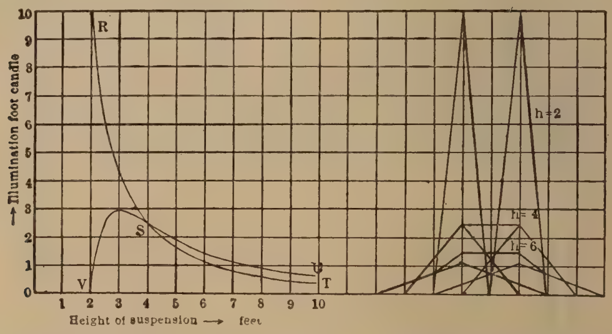

FIG. 29.—Effect of Height of Lamps on Distribution and Intensity of Illumination.

The preceding discussion by no means embodies the entire calculations pertaining to illumination. There are others less practical and still others involving long discussions and tedious mathematical deduction quite out of the scope of this lecture, although of great value to the student of illuminating engineering. That these different branches of the subject may be investigated further by those interested, the titles and references of some of the leading articles are incorporated in the following bibliography. For instance, the distribution of illumination in the neighborhood of a row of lamps No. 30, illumination from linear sources No. 31, and the calculation of radiation from surface sources No. 33 and No. 36, refer to special branches of the subject not entered upon by the writer.

There are also references to articles dealing with the subjects discussed in this paper and explaining the methods more in detail and to greater length.

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XIII (2)

THE PRINCIPLES AND DESIGN OF INTERIOR ILLUMINATION

By L. B. Marks

CONTENTS

Lecture I

Daylight

Artificial Light

Personal equation.
Color of the lighting source, and color of the ceiling, walls, floor and room furnishings.
Diffusion and direction of light.
Contrast.
Shadows.
Regular or specular reflection.
Intrinsic brightness, primary and secondary lighting sources.
Glare.
Selection of illuminant.
Location of lighting sources.
Fixtures: Globes, shades and reflectors.

LECTURE II

Systems of illumination:
- (1) General illumination by direct lighting.
  - (a) Lamps exposed to view.
  - (b) Lamps enclosed in globes or mounted behind a transmitting screen or septum.
- (2) General illumination by indirect lighting; primary lighting sources totally concealed from view and illumination carried out entirely by reflected light.
  - (a) Cove lighting.
  - (b) Lighting by lamps concealed in opaque reflectors suspended from the ceiling.
- (3) Local illumination. Lighting carried out entirely by lamps placed to localize the light on the work.
- (4) General illumination by combination of direct and indirect lighting.
  - (a) Direct lighting units supplemented by indirect lighting.
  - (b) Indirect lighting units supplemented by direct lighting.
  - (c) Combination of direct and indirect lighting in the same unit.
- (5) Combination of general and local illumination.
  - (a) General illumination, supplemented by localized lighting at places where a higher intensity of illumination is desired.
  - (b) Local illumination of such design as to provide general illumination.

Steadiness of light.
Aesthetic considerations.
Ventilation.
Safety.
Efficiency of lighting; cost of installation and cost of maintenance.
Efficiency of illuminating installation.
- (a) Efficiency of the lamps.
- (b) Gross efficiency of the illuminating installation.
- (c) Net efficiency, or efficiency of utilization of light.

Efficiency of direct and indirect lighting.

LECTURE III

Application of the Principles Set Forth in the Design of Illumination of Interiors

Study of the architect's plans of a building.
Plan of first floor of State, War and Navy Building, Washington, D. C.
Plan and elevation of typical room in State, War and Navy Building, showing proposed location of outlets.
Chart showing distribution of illumination on reference plane 2 ft. 6 in. above the floor, typical room, State, War and Navy Building.
Plan and elevation of typical corridor, showing proposed location of outlets, State, War and Navy Building.
Chart showing distribution of illumination in corridor, State, War and Navy Building.
Plan of first floor, Carnegie Library, New York City, showing location of outlets for a system of general illumination combined with local illumination.
Plan of assembly room and lecture hall, Carnegie Library, New York City, showing design of lighting system involving application of asymmetric distribution of light.
Sectional view of the building for the new National Museum, Washington, D. C., showing rotunda, dome and skylight.
Sectional view of rotunda dome, new National Museum, Washington, D. C., showing design of daylight prism skylight, adapted for natural and for artificial illumination.
Plan showing system of lighting a factory by strictly localized lamps.
Plan showing system of lighting a factory by local illumination of such design as to provide general lighting.
Curves showing distribution of daylight illumination and artificial illumination in a specific case of interior lighting.

LECTURE I

DAYLIGHT

Fundamental Principles of Daylight Illumination. In daylight we have such an enormous flux of light available for illumination, that the problem of adequately and suitably lighting an interior often resolves itself in the main simply into one of providing adequate window openings for the entrance of the light.

One of the simplest attempts to secure conditions favorable to good daylight illumination of interiors, consists in specifying the window space required for a given floor area. Thus, in some classes of interiors the ratio of the area of the window space to the floor area to be lighted, is sometimes specified to be 1 to 4 or 1 to 5, as in factories, for example; while in other classes, such as office buildings, this ratio is specified to be 1 to 7 or 1 to 10, etc., depending

to some extent upon the depth of the room. This system of computation, however, is evidently more or less limited in its application, for the ratio of window space to floor area for the lower floors of a building might be quite different than that of the upper floors for equivalent illumination, especially if part of the direct light of the sky is cut off by an adjacent tall building.

The amount of daylight that reaches the interior will depend not only upon the area of the window space, but upon (a) position of the windows, (b) the contour and depth of the windows, (c) the character of glassware in the windows, (d) the sky angle, which will depend upon the distance from and height of adjacent buildings, (e) the diffusion constant of the street and of adjacent buildings, and (f) upon the brightness of the sky.

Often only a very small percentage of the flux of daylight that reaches the window is effective in the illumination of the interior. The effect of blinds, curtains and other decorative and absorbent media in obstructing the entrance of light is considerable. Furthermore, if the color of the walls and furnishings is dark there may be considerable absorption of the light.

As pointed out by Dr. Waldram,* the proportion of daylight illumination that reaches interiors is very much smaller than is usually supposed. If the illumination of a piece of white paper be measured, first when the paper is placed on a table in the middle of an average room, and then when placed on a table outdoors in an open space, one finds a difference of say 1000 to 1 in favor of the latter position. To anyone considering the matter for the first time, such a condition seems impossible; most people looking at the piece of paper in the two positions would estimate the respective illuminations at say 2 to 1 or 3 to 1, and would consider even 100 to 1 ridiculous. The difference, however, does not seem so startling when it is remembered that under the same conditions a photograph of any outside view might require say one-fifth of a second, while the necessary exposure for an interior might well be, say 5 minutes with the same stop, a difference of 1500 to 1.

Hence, though we may have an intensity of daylight illumination on the windows all the way from 50 to 500 foot-candles (about 500 to 5000 meter-candles), under varying conditions, unless suit-

* "The Measurement of the Relation between Daylight Illumination of Rooms and Sky Brightness." By Dr. P. J. Waldram. Illuminating Engineer, London, Vol. I, 1908, p. 811.

able provision is made for directing the light into the interior only a very small percentage of this intensity may be of use in lighting the working spaces.

Brightness of the Sky

We may classify the sources of daylight broadly as follows:

Primary Source. (1) Sunshine.

Secondary Sources. (2) Cloud light or white skylight derived from scattered sunshine; (3) blue skylight from the air; (4) diffused light reflected or re-reflected from objects illuminated from the above sources.

In the consideration of daylight illumination, cognizance must be taken principally of the secondary lighting sources, and of the effect which the variation in these sources produces on the resultant illumination of an interior.

In planning for the daylight illumination of interiors, we must provide for adequate illumination under the varying conditions that obtain in daylight; that is to say, we must plan our window openings, etc., to provide for the minimum as well as the maximum value of daylight. There is a great variation in the intensity of daylight with different classes of sky.

One of the first attempts to obtain a reliable estimate of the brightness of the sky was made in Chicago by the American Luxfer Prism Company, in 1897. In this investigation, the kinds of sky were arbitrarily divided into the following five classes:

Class 1. Clouds, no blue sky, no sun, storm present or near.

Class 2. Cloudless, either clear blue or hazy.

Class 3. Blue predominating; clouds generally cirrus.

Class 4. Clouds predominating; general cumulus.

Class 5. Overcast, no blue.

In Fig. 1 these classes of sky are arranged in the order named, the mean brightness of each class being plotted to the vertical scale.

In these tests the brightness of the sky was measured by a flicker photometer in the following manner:

A photometer room was located on the top floor of a building, in the roof of which was provided a circular aperture capable of adjustment between 3 inches (7.6 cm.) and 5 inches (12.7 cm.) in diameter. The direct light of the sky penetrated the room through this aperture and was received on a photometer screen located 8 feet (2.44 meters) below the aperture. The illumination from the

sky was balanced by that of an incandescent lamp in the usual manner.

An examination of the chart brings out the striking fact that the actual illumination on a cloudy day with the sun overcast (Class 5 sky) is about double the illumination on a perfectly clear day (Class 2 sky).

In planning the daylight illumination of interiors, provision should be made, as far as practicable, for adequate lighting under conditions of minimum sky brightness.

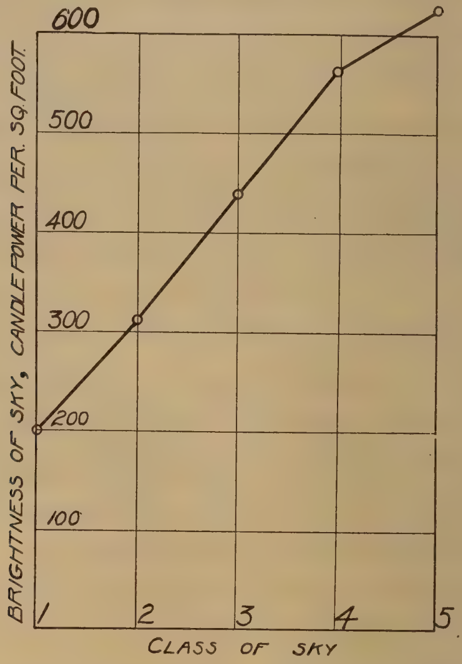


FIG. 1.—Daylight. Relation Between Class and Brightness of Sky.
1. Clouds, no blue sky, no sun, storm present or near.
2. Cloudless, either clear blue or hazy.
3. Blue predominating—clouds generally cirrus.
4. Clouds predominating—generally cumulus.
5. Overcast, no blue.

Dr. S. Ruzicka * concludes from a series of measurements of daylight illumination that for good results the minimum intensity of daylight in an interior on a dark and cloudy day should not fall below 1 per cent of the sky brightness. With Class 1 sky (Fig. 1) this minimum would be about 2 foot-candles (21.5 meter-candles).

* Die relative Photometrie. S. Ruzicka. Archiv. f. Hygiene, 1907.

Diffusion and Direction of Daylight through Windows

The diffusion of light through different kinds of glass is strikingly shown in a series of photographs published in a report submitted to the Insurance Engineering Experiment Station, Boston.* These photographs were obtained by placing a bright Argand gas burner on one side of a slit about 2½ inches (6.35 cm.) long by ½ inch (1.27 cm.) wide, the specimen of glass being placed close to the other side of the slit. Figs. 2 to 7, inclusive, show the results obtained for the following types of glass:

Fig. 2. Clear plate glass.

Fig. 3. Rough plate glass.

Figs. 4 and 5. Two specimens of fancy prismatic glass.

Fig. 6. Ribbed glass flattened on outer curves.

Fig. 7. Factory ribbed glass, with true curves, 21 ribs to the inch.

It will be noted that with clear plate glass there was no diffusion, with rough plate glass only a light diffusion, with fancy prismatic glass a very irregular diffusion, with ribbed glass flattened on outer curves a moderately good diffusion, and with factory ribbed glass almost perfect diffusion.

In the same report are recorded the results of tests of Prof. C. L. Norton, of the Massachusetts Institute of Technology, showing the direction and diffusion of light under stated conditions in a room 53 feet (16.15 m.) deep and 41 feet (12.5 m.) wide. At a height of 8 feet (2.44 m.) above the floor an opening 12 inches square (929 sq. cm.) was left in a large window. All other openings by which light might enter the room were closed. Photographs of the room were taken when bright sun was shining upon the window. Prof. Norton states that all were exposed, developed and printed under the same conditions. The illustration (Fig. 8) shows the average distribution of light in such a room with (1) plane glass, (2) factory ribbed glass, (3) maze glass, and (4) prismatic glass. These drawings show more clearly than would a lengthy description, the change in the distribution of illumination, due to the diffusion and direction of light through these four specific types of glass. The interior of the room is shown in perspective, as if one side were removed.

* Report No. 3, "Diffusion of Light," Insurance Engineering Experiment Station, Edward Atkinson, Director, Boston, September, 1902.

FIG. 2.—Clear Plate Glass.

FIG. 3.—Rough Plate Glass.

Fig. 4.—Fancy Prismatic Glass, 1st Specimen.

Fig. 5.—Fancy Prismatic Glass, 2d Specimen.

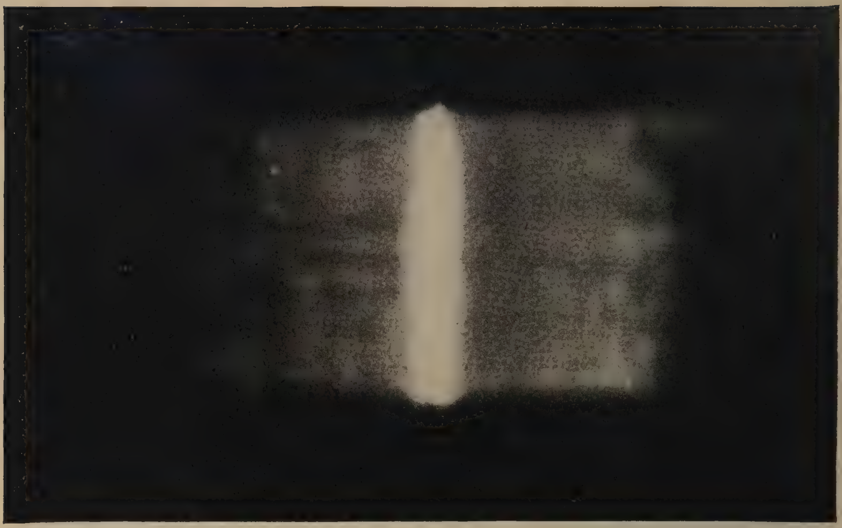


FIG. 6.—Ribbed Glass, Flattened on Outer Curves.

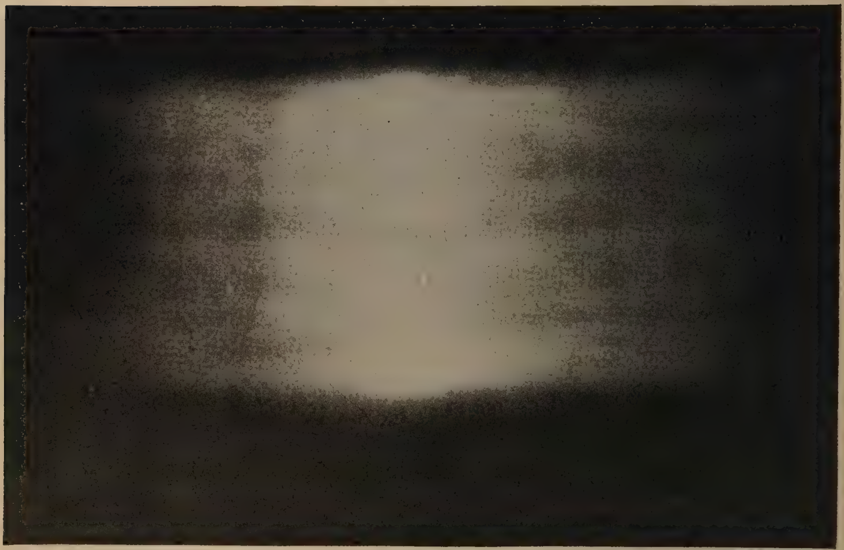


FIG. 7.—Factory Ribbed Glass, with True Curves, 21 Ribs to the Inch.

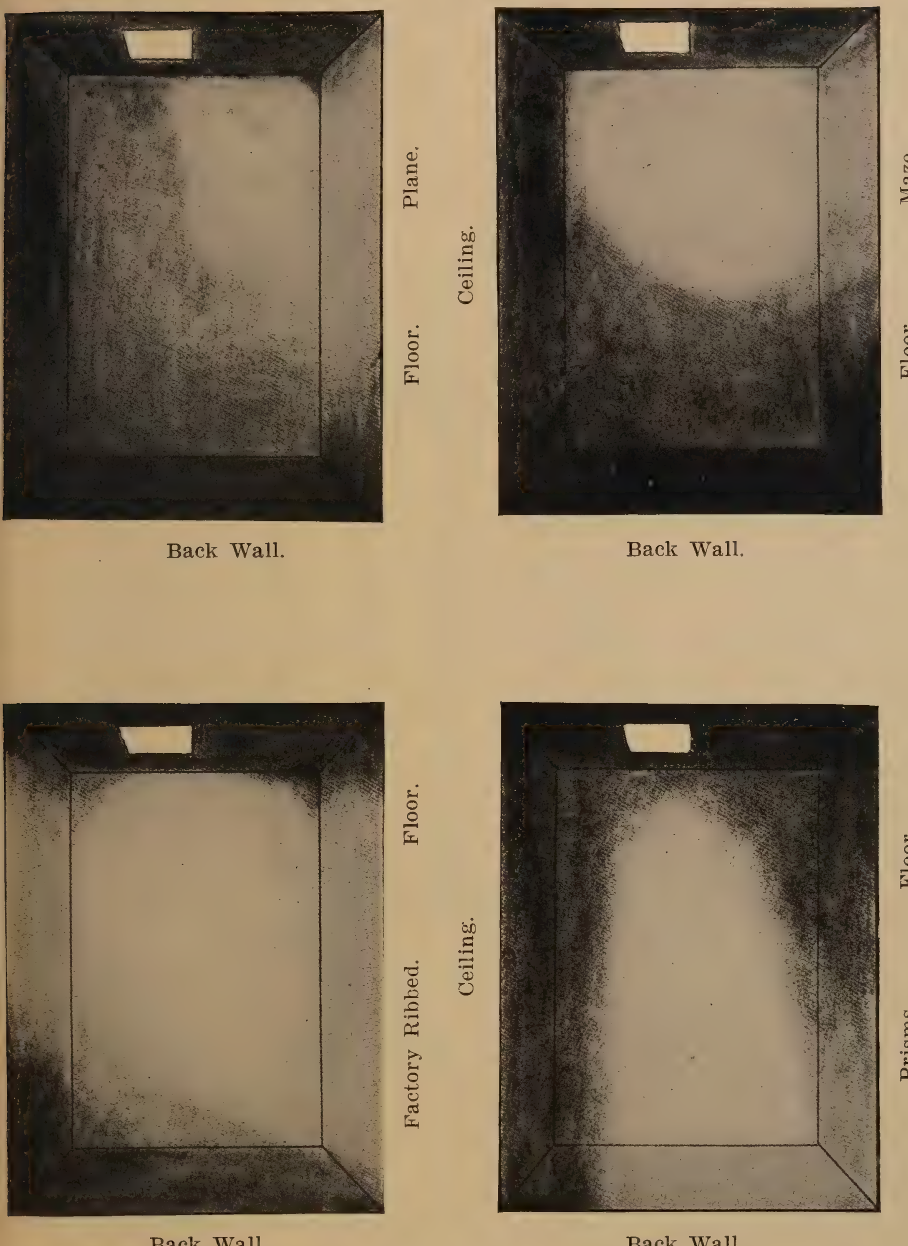
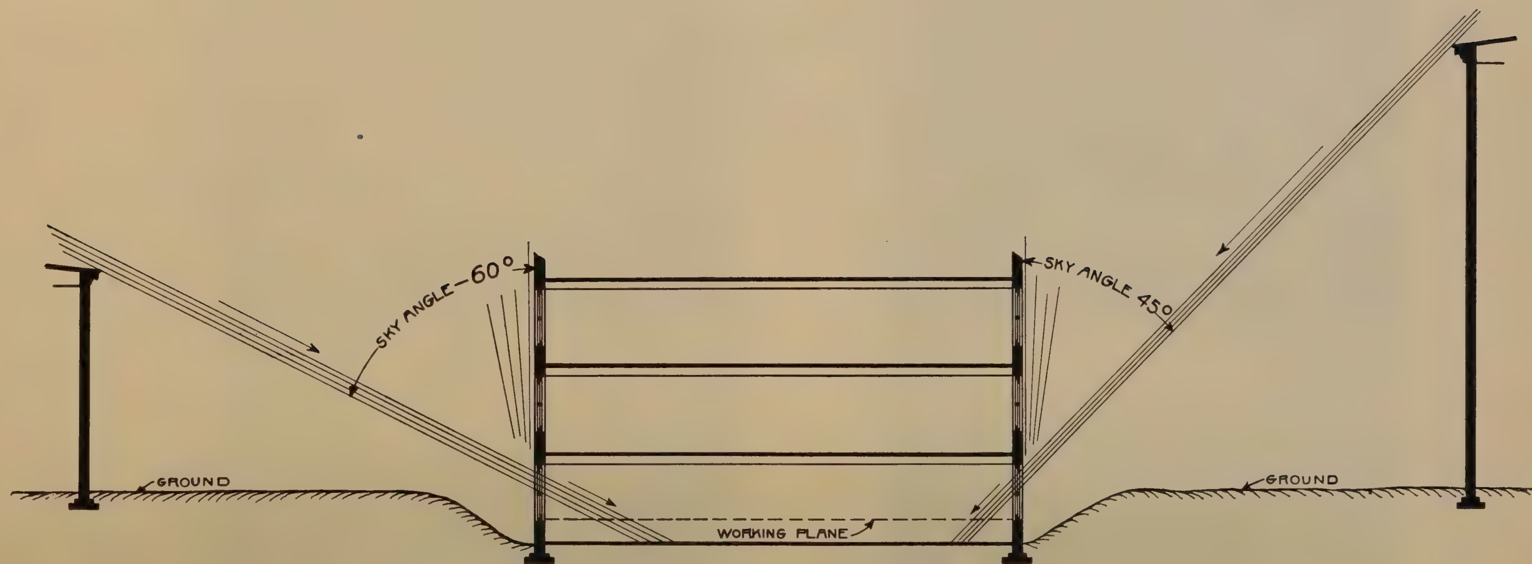


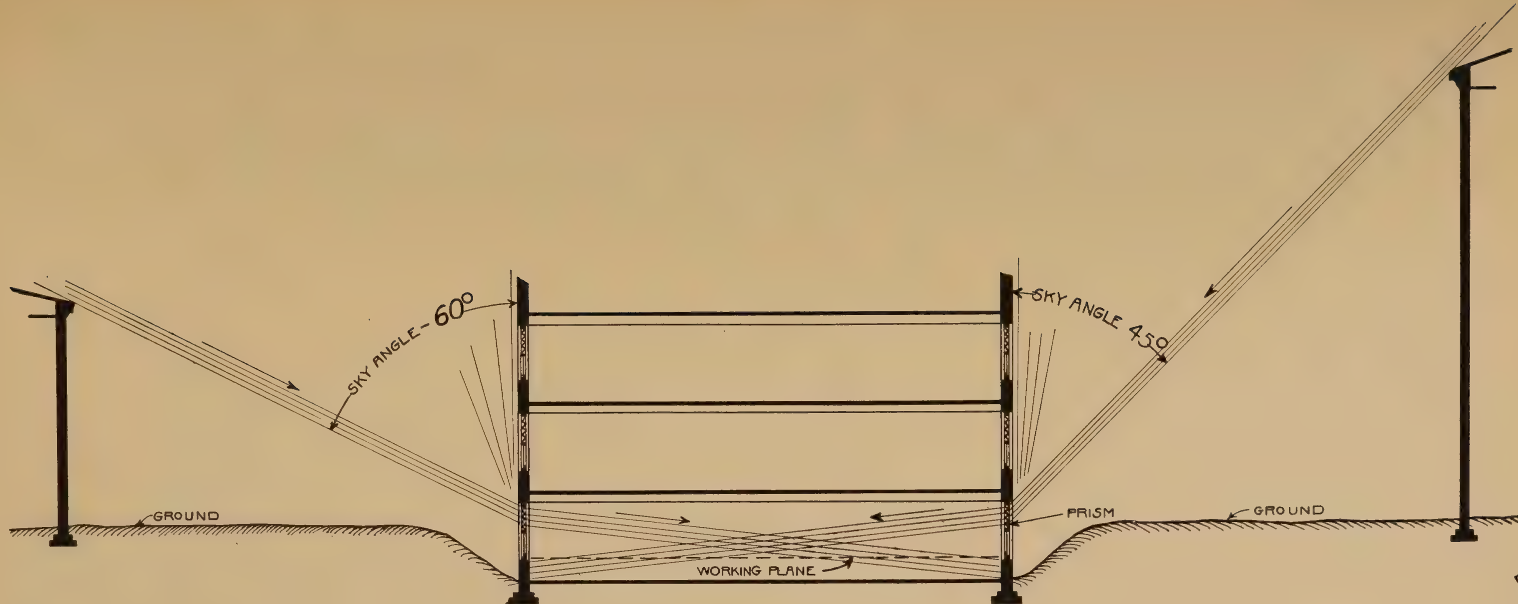
FIG. 8.—Distribution of Light in a Room Equipped with (1) Plain Glass, (2) Factory Ribbed Glass, (3) Maze Glass, (4) Prismatic Glass.

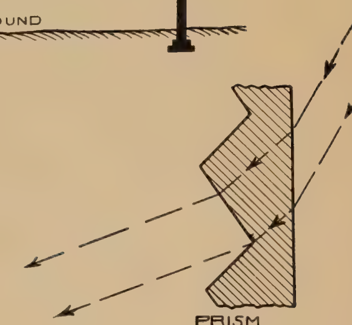


DAYLIGHT

CROSS-SECTION OF BUILDING SHOWING NATURAL DIRECTION OF LIGHT THROUGH ORDINARY WINDOWS IN BASEMENT WITH SKY ANGLES OF 45° AND 60° RESPECTIVELY

FIG. 9.





DAYLIGHT

CROSS-SECTION OF BUILDING SHOWING DIRECTION OF LIGHT THROUGH WINDOWS EQUIPPED WITH DAYLIGHT PRISMS DESIGNED TO SUITABLY DIRECT THE LIGHT FOR SKY ANGLES OF 45° AND 60° RESPECTIVELY

FIG. 9a.

The results of tests by Prof. Norton of a score or more of different types of window glass may be stated briefly as follows: We may increase the effective light in a room 30 feet (9.14 m.) deep or more, to from three to fifteen times by using factory ribbed glass instead of plane glass in the upper sash of the window. By using prisms, instead of plane glass, we may, under certain conditions, increase the effective light fifty times. The gain in effective light on substituting ribbed glass or prisms for plane glass, is much greater when the sky angle is small, as in the case of windows opening upon light shafts or narrow alleys. The increase in the strength of the light directly opposite a window in which ribbed glass or prisms have been substituted for plane glass is at times such as to light a desk or table 50 feet (15.24 m.) from the window better than one 20 feet (6.1 m.) from the window had previously been lighted.

Consideration of Exposure and Sky Angle in Planning the Illumination of an Interior

In planning the daylight illumination of an interior, careful consideration should be given to the exposure of the building and the sky angle; that is, the angle formed by a vertical line passing through a window in the wall of the building, and a line from the window through the top of the opposite building. While the exposure of the upper floors of a building may be such as to permit of free access of light to the interior, the lower floors of the building may be partially, or largely, shut off from direct light, and unless some means be employed for altering the natural direction of daylight which reaches the windows in the lower floors, the illumination of the interior of this part of the building may suffer accordingly.

In Figs. 9 and 9a is given the cross-section of a building showing, first, the natural direction of light through ordinary windows in the basement with sky angles of 45° and 60°, respectively, and, second, the altered direction of the light where the windows are equipped with daylight prisms designed to suitably direct the light for these sky angles.

It will be noted from the illustration that when ordinary plane-glass windows are used, the emergent rays strike the floor at points comparatively near to the windows, and a large part of the working plane receives no direct light. When the windows are equipped

with prismatic glass, as described, the incident rays are deflected from the course which they would naturally take if plane-glass windows were used, and instead of striking the floor at points near the position of entry of the light, reach the inner portions of the room, thus directly lighting the whole of the working plane, as shown in the illustration.

The economic value of the substitution of prismatic glass for plane glass in a case of this kind will be manifest. For example, in one mill in New England in which this change was made, the reaching power of the light in the remodeled installation was such that it was possible to dispense with eight skylight wells on two floors, thus permitting of the use of 10,800 square feet (about 1000 sq. m.) of additional floor space for manufacturing purposes.

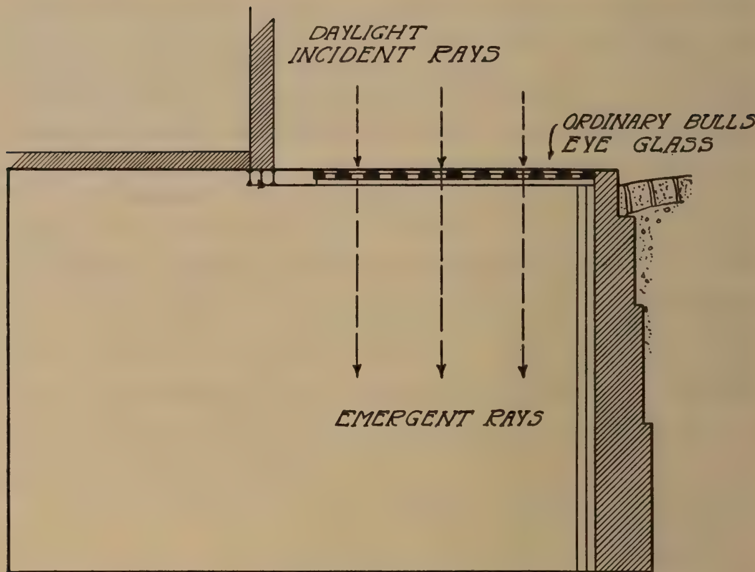
In the crowded tenement districts of large cities, the substitution of daylight prisms for ordinary window glass would be a boon to those unfortunates who are now compelled to live in rooms that scarcely see the light of day.

In Fig. 10 we have an illustration of the direction of light through glassware in the sidewalk over a basement space. This sidewalk is exposed to the direct light of the sky. It will be noted that with ordinary bull's-eye glass, the light, for the most part, passes directly downward, whereas with sidewalk directing prisms a large proportion of the light emerges at an angle, and reaches the floor at points more distant from the sidewalk than in the case of the bull's-eye glass. The drawings show only the characteristic direction of the emergent rays when ordinary bull's-eye glass and sidewalk directing prisms, respectively, are used. In the case of both of these types of glass, there will be some diffusion in all directions, but the general direction of a large proportion of the light will be strikingly different in the two cases, as shown in the illustration.

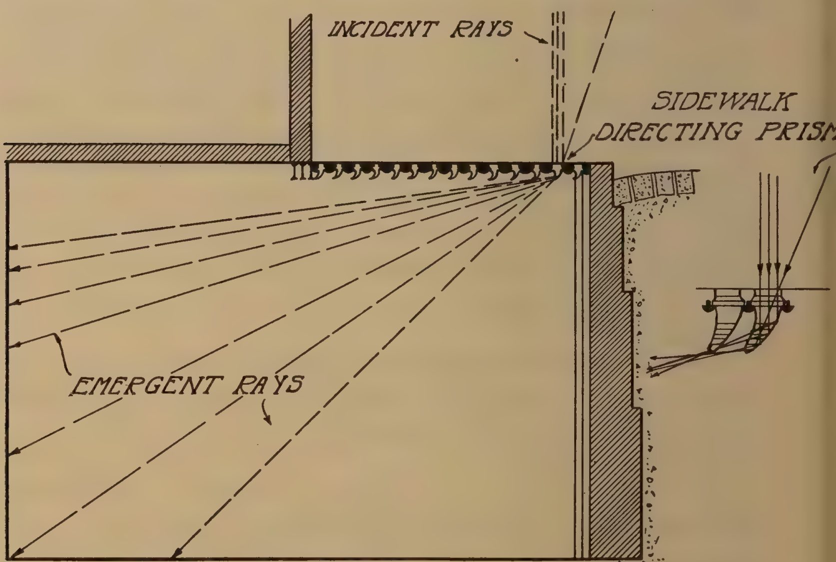
Dr. Waldram * has suggested the possibility of reproducing the daylight conditions of actual rooms in small models, and utilizing such models to study the various effects produced by variations in essential conditions.

For instance, a model can be temporarily papered with samples of different wall papers, and their different effects noted. Every possible condition of obscured horizon can be built up of sheets of paper or cardboard, having reflection coefficients identical with

* Loc. cit.



Direction of Light Through Ordinary Bull's-eye Glass in Sidewalk.



Direction of Light Through Sidewalk Prisms.

FIG. 10.

those of known building materials. The relative lighting capacity of every square foot of wall surface can be separately found for every degree of obstruction, and for any given distance back from the window wall; and, in fact, practical conditions can be reproduced, measured and standardized, so that the essential conditions for any given window efficiency can be accurately predetermined by simple calculation. The average number of hours during which natural light must be supplemented by artificial light over any given period can be directly obtained for any given window efficiency from yearly tables of average sky brightness.

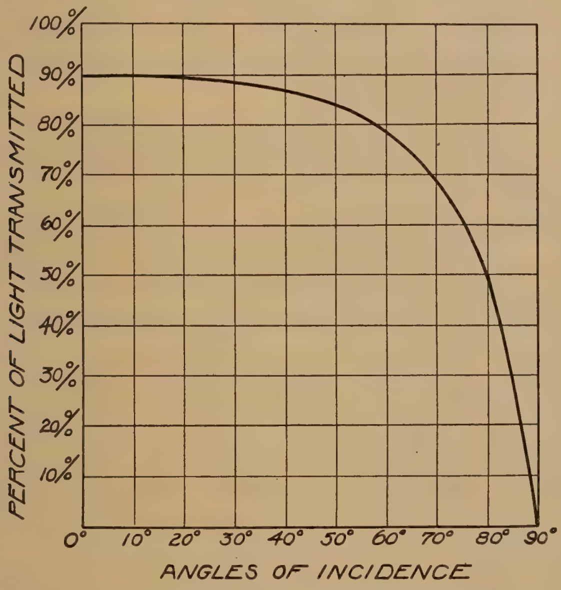


FIG. 11.—Daylight. Relation Between Angle of Incidence, and Transmission of Light Through Plain Window Glass

Relation between Angle of Incidence and Transmission of Daylight through Plain Window Glass

Plain window glass is generally said to cut off about 10 per cent of the light incident upon it. This is approximately true for angles of incidence smaller than 30°, but is not true for large angles of incidence. The curve (Fig. 11) shows the percentage of daylight transmitted through a plain glass window at angles of incidence from 0 to 90°. It will be noted that when the angle of incidence of the light is from 60° to 70°—a condition which is

frequently found in practice—from 20 per cent to 30 per cent of the incident light is lost. At an angle of incidence 80°, only 50 per cent of the incident light is transmitted through the window. By the use of directing prisms, a large percentage of the light thus lost may be made available.

Diffusion Constant of Building Front

In planning the daylight illumination of an interior we must take into account the proximity and height of other buildings, and also the color of these buildings.

In many cases the flux of light that reaches the windows of an interior will depend to a considerable extent on the diffused light from the building fronts and street surface. This flux is made up of two components, as follows:

(1) That portion due to the direct light of the sky.

(2) That portion due to the diffusion of light from buildings and street surface.

There are multiple diffusions from buildings and street surface, but the effect of all diffusions after the third is so slight that for all practical purposes in illuminating design we may consider only the effect of the direct light of the sky and of the first three diffusions of light from buildings and street surface. The curves * (Fig. 12) show the relation between the illumination of a window 10 feet (3.05 m.) from the ground level, and the diffusion constant of the building fronts and street surface, and refer to the diffusion in a street 80 feet (24.4 m.) in width with buildings 140 feet (42.7 m.) high on each side—the average condition in the newer parts of the City of Chicago. The sky is assumed to have a brightness of 250 candles per square foot (2690 candles per sq. m.)—an average value which obtains in a cloudless sky, and the street surface is assumed to have a diffusion constant of 8 per cent. The abscissae are the diffusion constants of the building fronts (assumed as varying), and the ordinates refer to the illumination of a point in the window 10 feet (3.05 m.) from the sidewalk—taken to represent an average value for the ground floor.

Below the curve 1 (Fig. 12) is the illumination due directly to the sky. Between curves 1 and 2 is the illumination due to the first diffusion from the street surface. Between curves 2 and 3 is

* C. O. Basquin, "Daylight Illumination," Illum. Eng., New York, Vol. II, 1907-8, p. 451.

the illumination due to the first diffusion from the opposite buildings. Between curves 3 and 4 is the illumination due to the second diffusion, and between curves 4 and 5 that due to the third diffusion.

It will be noted from the curves that after the third diffusion the lighting effect is practically negligible. When the diffusion constant is 50 per cent (a value which is found in practice with white-tiled building fronts) the increase in the illumination of the

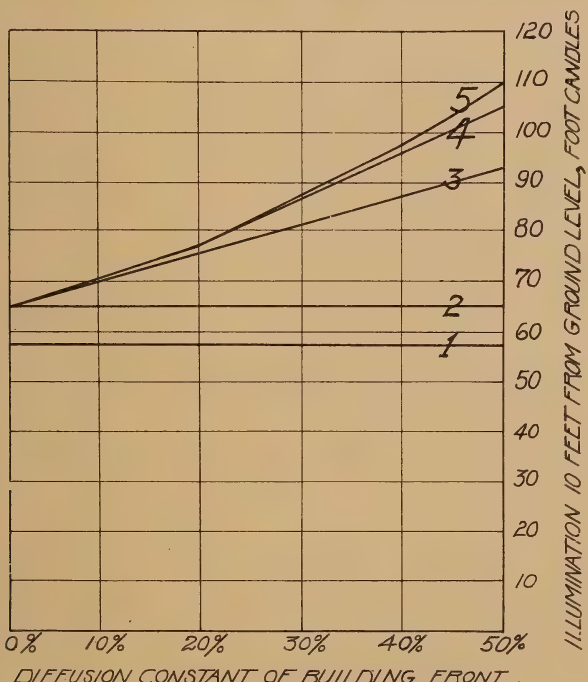


FIG. 12.—Daylight. Relation Between Illumination and Diffusion of Light From Buildings and Street.

Distance between buildings, 80 feet. Height of opposite building, 140 feet.

Brightness of sky, 250 candle-power per square foot.

Diffusion constant of street surface, 8 per cent.

1. Illumination due directly to the sky.
2. Illumination due to (1) plus illumination due to first diffusion from street surface.
3. Illumination due to (1) and (2) plus illumination due to first diffusion from opposite building.
4. Illumination due to (1), (2) and (3) plus illumination due to second diffusion from opposite building.
5. Illumination due to (1), (2), (3) and (4) plus illumination due to third diffusion from opposite building.

ground-floor fronts is almost equal to the direct illumination from the sky; in other words, the effective illumination in the interior is, in this case, increased 100 per cent by diffusion from opposite buildings.

Dr. Basquin points out that a number of white-tile buildings have been erected in Chicago, and suggests that public appreciation of such advantages to the city should be encouraged. When the city has become covered with tall buildings, both dark and dirty, the need of tile fronts, light in color and easily cleaned, will be evident to all.

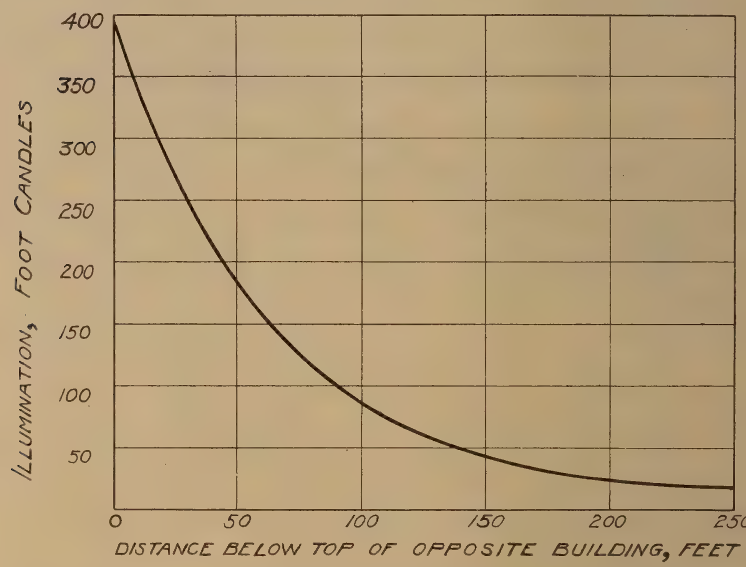


FIG. 13.—Daylight. Relation Between Illumination of a Building and Height of Opposite Building.
Distance between buildings, 80 feet.
Brightness of Sky, 250 candle-power per square foot.

Relation between Illumination of Building and Height of Opposite Building

The curve shown in Fig. 13, due to Basquin, illustrates the manner in which the illumination on the building front varies with the distance of the point of observation below the top of the opposite building front. The curve is drawn to correspond with the average condition in the loop district of Chicago, where the street width is 80 feet (24.4 m.). The brightness of the sky is assumed to be

250 candles per square foot (2690 candles per sq. m.)—an average value. The abscissae of the curve represent the distance of a window or point of observation, below the level of the top of the opposite building. The ordinates represent the intensity of illumination at this point, in foot-candles.

The Chicago building ordinance of 1905 limits the maximum height of building front to 260 feet (79.25 m.). In this connection, in illustration of the use of the curve (Fig. 13), let us assume that there are old buildings 75 feet (22.9 m.) high on each side of the street. The illumination at a point 5 feet (1.5 m.) from the sidewalk is then seen from the figure to be about 135 foot-candles (1453 meter-candles). This may be taken to represent the average condition in the City of Chicago up to about the year 1890, and is fairly representative of many cities at the present time.

Let us now assume that one of these buildings is raised to 140 feet (42.7 m.) in height—the average height of the modern buildings. The curve shows that the illumination on the opposite side under this condition, at 5 feet (1.5 m.) from the sidewalk, will be about 52 foot-candles (560 meter-candles). When the buildings have reached the height of 260 feet (79.25 m.), then we see, at the bottom of the curve, that the illumination for the ground floors will be reduced to about 18 foot-candles (194 meter-candles), or less than one-seventh of its value when all buildings were four stories high.

ARTIFICIAL LIGHT

The General Problem of Artificial Illumination Compared with that of Daylight. Natural light has always been the criterion of that which is most desirable to obtain by artificial lighting. The broad problem in artificial lighting is how to obtain, with the comparatively feeble flux of light we have at our command from artificial sources, as close an approach as possible to the character of lighting obtained from the enormous flux of daylight. With the well-known limitations of artificial light, it would, at first sight, appear impossible to reproduce in effect the conditions which obtain in daylight illumination.

The development of the science of illuminating engineering has, however, demonstrated that step by step we are changing our methods of artificial lighting and approaching more nearly the ideal

conditions. The handicap of artificial light is not nearly so great as would appear.

Contrast the problem of daylight illumination with that of artificial lighting. We have, on the one hand, a tremendous flux of light and an enormous area from which the light comes, and, on the other, an extremely limited flux and, usually, a comparatively small area from which the light comes. Fortunately, the eye is so constituted that we are capable of good vision between an extremely wide range of luminous intensities. We may see well, and without visual fatigue, in daylight at an intensity of 500 foot-candles (about 5000 meter-candles) and more, and at 1 foot-candle (about 10 meter-candles) and less. Under good conditions of artificial lighting we may see well, and without visual fatigue, at several hundred foot-candles intensity and at less than 1-foot-candle intensity.

The ability of the eye to adjust itself to very low-working intensities of illumination makes it possible to simulate daylight conditions in the design of the artificial lighting of interiors. While we recognize this possibility, we realize that before the eventuality of an ideal design there remains to be performed a mass of experimental work, investigation and research, involving a close analysis of conditions of illumination of which we have practically no data at present, and, in general, a complete study of the problem from the physical, physiological and psychological standpoints.

Up to the present time, lighting by artificial sources has, for the most part, been carried on by illumination from substantially point sources. These are the sources with which we have to do for the most part at present, and which will continue to occupy our attention in the immediate future.

Fundamental Principles of the Artificial Illumination of Interiors. In studying the principles underlying the application of artificial light to the illumination of interiors, we must consider, broadly, the following:

1. Flux of light.
2. Diffusion and direction of light.
3. Quality or color of light.

The study of the above involves the consideration of:

A. The character of the illuminant.

B. Intensity of illumination.

C. System of illumination.

D. Location of lighting sources.
E. Lighting fixtures: Globes, shades and reflectors.
F. Glare: intrinsic brightness.
G. Regular or specular reflection.
H. Contrast.
I. Shadows.
J. Aesthetic considerations.
K. Economy and efficiency.

The above headings are not arranged in the order of their importance. In fact, it would be difficult, if not impossible, to name any one item in the list which could be said to be less important than another. The violation of a single principle of illumination, no matter how seemingly trivial the violation may be, may make the difference between success and failure in the accomplishment of the desired result.

1. *Flux of Light*

The flux of light required for the adequate and suitable illumination of the interior will depend upon a variety of conditions. The governing consideration in all cases is, of course, the ability to see well, but coupled with this must be visual comfort while occupying the interior, whether for a short or a prolonged period of time. Unless all of the conditions of usage of the light and of equipment of the interior are definitely defined, it is impossible to state in advance, with any degree of precision, what flux of light will be required to supply adequate and suitable illumination.

The flux of light required for the illumination of a given interior will depend (a) upon the actual intensity necessary on the work or on the objects viewed, and this in turn will depend upon (b) the system of lighting employed; (c) the location of lighting sources with reference to the field of view; (d) the intrinsic brightness of the lighting sources; (e) the contrast in the degree of illumination in different parts of the interior; (f) the extent of regular or specular reflection from the objects viewed; (g) the color of the light and the color of the ceilings, walls, floor and room furnishings, and (h) upon the personal equation of the user.

In determining the flux of light required for the illumination of an interior, it is customary to assume a definite intensity on a reference plane, usually a horizontal working plane 2 feet 6 inches (0.76 m.) above the floor. Based on experience in existing light-

ing installations, we know that the flux of light required to give the needed intensity may vary between very wide limits, depending upon conditions which have been named above.

In determining the total flux needed, the method employed at present is to assume certain intensities that have been found in practice to be nearest the desideratum under well-defined conditions that have been established in a parallel case.

2. Diffusion and Direction of Light

In daylight illumination of interiors, we have a natural diffusion of light, as well as definite direction. In illumination by artificial light, however, we find it very difficult to reproduce these conditions, and are often compelled to sacrifice diffusion for direction or vice versa.

The layman in considering the illumination of an interior by artificial light sees little more in the problem than hanging a sufficiently powerful light in the center of the room, and possibly supplementing this by a number of side lights around the room. His idea usually is that if a sufficiently large flux of light is provided, all that remains to be done is to select lighting fixtures that suit his taste, and it is no uncommon experience to find that the owner of a building, be it a residence, a store or an auditorium, selects his lighting fixtures from a stock in the open market, having regard mainly, if not only, for the cost of the fixture equipment and its general appearance. He is not apt to take cognizance of the question of suitable diffusion and direction of the light.

The lighting design should provide for such a diffusion of light as to avoid striking contrasts in different parts of an interior. To accomplish this result, it is necessary to provide for the emission of a suitable proportion of the light rays in an upward and sideward direction to illuminate the ceiling and walls to a moderate intensity, and to direct a suitable proportion of the light downward and sideward to illuminate more brightly the "working" portions of the room.

3. Quality or Color of Light

The quality or color of the light, and the color of ceilings, walls and furnishings, of an interior have an important bearing not only on the flux of light required to give a definite intensity of illumination on the objects viewed, but also on the ability to see

well with this intensity. Our conception of true color values of surfaces is based upon the values which obtain in daylight illumination. Correct color values cannot be obtained from light which is deficient in rays, which a surface must reflect in order to be seen in its natural color.

From the standpoint of securing true color values our choice of artificial illuminants is extremely limited. In practice, however, even with this limitation, we can secure results from artificial light fairly comparable with those obtained in daylight, by adapting the illuminant so far as possible to the conditions to be met in each individual case.

A. Selection of Illuminant. As between illuminating gas, electric light, acetylene, oil and candles, we find in practice conditions in which some one of these illuminants is better suited to the needs of the user than any of the others. Generally speaking, however, the question is, what type of gas lamp or what type of electric lamp is best adapted for the lighting of a specific interior.

In the selection of an illuminant the following factors must be considered:

(a) The difference in first cost and cost of maintenance of two types of lamps, each having substantially the same efficiency of utilization of light, may be a determining factor in the choice of the type of illuminant.

(b) The quality or color of the light for the purposes in hand may likewise be a determining factor in the choice of the type of lamp. Thus, for example, in the home, the choice may be limited to illuminants capable of producing a mellow light. In a factory, on the other hand, especially where considerable smoke is present, the flaming carbon arc lamp, because of the color of its light rays, may be better adapted to the requirements than any other type of lamp. Again, in a department store an intensified carbon arc lamp may, in some cases, furnish the desired brilliancy and color values where most other lamps fall short. In the post-office work room, where the bulk of the work consists in reading printed or written matter on white background, the mercury arc lamp may best meet the requirements of visual acuity.

(c) The divisibility of the lighting unit, that is, the sizes in which the unit may be procured, may be the deciding factor in the selection of the type of lamp best suited for the conditions in

hand. The suitable divisibility of the unit would depend upon the size of the interior, architectural, aesthetic and other considerations. It may be very important to select an illuminant that will be capable of such division that the lighting will not be seriously impaired if one or more of the lamps accidentally go out of commission.

(d) The ability to direct or redirect the light of the lamp by suitable reflectors or diffusers may be a governing condition in selecting the type of lamp best suited to meet the needs in a given case.

(e) In some cases the selection of an electric lamp may depend upon the character of current available. For example, where only the ordinary constant-potential direct current is available, the use of low-voltage tungsten lamps may be precluded, and likewise the use of the vacuum-tube lamp; whereas, with alternating current, the choice might fall to one of these types of lamps.

Aside from the question of maintenance cost, the long life *per se* of a lamp may be a governing condition in cases where freedom from care of trimming or replacing the lamp is of paramount importance.

(f) A primal consideration in the selection of a lighting source is, of course, that the light should be perfectly steady under all conditions of operation. The eye-strain which results from an unsteady or flickering light need not be dwelt upon here.

Where the eye is taxed continuously with the discrimination or discernment of fine details, as, for example, in the work of engraving, or where the task is that of reading a book or newspaper, the importance of having a steady light is naturally very considerably greater than where only casual observations of illuminated objects are necessary, or where the eye is not called upon to discern the details, as, for example, in foundries where the work is bulky and the only operation is that of casting large ingots which require no detailed inspection.

In the case of open-flame burners, the question of suitable protection of the flame from drafts and air currents, to insure best conditions of steadiness of light, must be taken into account.

The selection of a lighting source, be it gas or electricity, that will give good results as to steadiness, not only under conditions of constant pressure but also under service conditions of more or less variability in pressure, must be considered. Certain types of

lamps will burn steadier than others on electric circuits having a low periodicity. The selection of a lamp may, therefore, have to be made with reference to the particular circuit on which the lamp is to operate if the best results as to steadiness are to be secured.

Even with the usual periodicity of 60 cycles on alternating-current circuits, the passage of the current through the zero point may be accompanied by a noticeable tremolo in some types of lamps, as, for example, in the vacuum-tube lamp.

In a stroboscopic test reported by Dr. E. P. Hyde and J. E. Woodwell,* it was found that the ratio of the instantaneous value of the maximum and minimum illumination from a vacuum tube operated on a 60-cycle alternating-current circuit was 8 to 1. When two tubes were put on separate phases 90° apart, the visible fluctuations in the instantaneous value of the illumination were greatly decreased, and the ratio of maximum to minimum was reduced to 2 to 1, as compared with a ratio of 8 to 1 with a tube running on single phase.

These results show that in planning the illumination of an interior a simple precaution in the design may in some cases make a great difference in the steadiness of the light.

(g) The vitiation of the atmosphere is another feature that must be taken into consideration in planning the lighting of an interior.

(h) The general proposition of safety or immunity from fire risk in the use of an illuminant is one that must be considered in planning the lighting of an interior. Because of this feature, the choice of an illuminant is often restricted to lamps in which the light-giving source is hermetically sealed.

(i) The choice of the kind of lamp to be used will often depend upon the system of lighting employed.

(j) The flexibility of the system and the ease of control of the lamps may also be a deciding factor in the selection of an illuminant.

B. Intensity of Illumination. The intensity of illumination required for good vision will depend not only upon the character of the work to be performed, but upon a number of conditions which have already been named. Tables have been published from time

* Transactions I. E. S., November, 1909, Tests of Moore Tube Installation.

to time stating the intensity of illumination required for special classes of service. According to some of these tables, the intensity of illumination required for different classes of buildings and different kinds of work are as follows:

Residences, from 1 to 2 foot-candles (about 10 to 20 meter-candles).

School rooms, from 2 to 3 foot-candles (about 20 to 30 meter-candles).

Libraries, from 1 to 2 foot-candles (10 to 20 meter-candles), in general, and 3 to 4 foot-candles (30 to 40 meter-candles) on the reading tables.

Factories, from 4 to 5 foot-candles (40 to 50 meter-candles) where no individual local lamps are used, and from 2 to 3 foot-candles (20 to 30 meter-candles), general lighting, where individual lamps supplement the general lighting.

Figures are also given for the illumination intensity required for different kinds of work, as, for example:

For drafting, from 5 to 10 foot-candles (50 to 100 meter-candles).

For engraving, 5 to 15 foot-candles (50 to 150 meter-candles).

For postal service, 2 to 5 foot-candles (20 to 50 meter-candles), etc.

Where such figures are given they should be interpreted only in the light of the specific conditions under which the lamps were used, otherwise they may lead to entirely erroneous conclusions. It is difficult, if not impossible, to state definitely what illumination intensity is required in any instance without limiting the statement by a long list of conditions, some of which, with our present imperfect knowledge of the art, could not even be definitely set forth. Hence, while it is stated, for example, that the intensity of illumination required on the reading table of a library is from 3 to 4 foot-candles (30 to 40 meter-candles), the specific conditions attending the use of the light must all be known before it would be safe to so assume that substantially the same results would be achieved if an intensity of from 3 to 4 foot-candles (30 to 40 meter-candles) were provided on the reading table of another library which it was desired to illuminate. Under changed conditions it might easily be that 1 or 2 foot-candles (10 to 20 meter-candles) would be sufficient, or that 4 foot-candles (40 meter-candles) would be insufficient.

A striking example of the relativity of illumination intensity required for a particular class of work was noted by me in a factory installation in which the operators had become accustomed to an intensity of approximately 20 foot-candles (215 meter-candles) on the work, and in which it appeared that this intensity was absolutely required to enable them to see the work clearly. In the case under discussion, the localized system of drop lamps was used, each machine being provided with 2 individual lamps, backed by opaque reflectors which shielded the eyes from the light of the lamp.

It was found that by substituting a system of general lighting by which the entire room was moderately illuminated, while at the same time a considerable proportion of the light of the lamps was directed to the machines, the operators could actually see the work better, even though the intensity of illumination on the work was reduced from about 20 foot-candles (215 meter-candles) to from 4 to 6 foot-candles (43 to 64.5 meter-candles). The need of a high intensity with the local system of lighting, as first used in this factory, was undoubtedly due primarily to the effects of the strong contrast in the intensity of illumination on different parts of the machine. This contrast will be appreciated on examining the chart (Fig. 14),* which speaks for itself.

In this chart, the illumination intensities for the two systems of artificial lighting, and the illumination intensity in daylight are given. It was found that under the conditions that obtained in this factory, the daylight was sufficient when the intensity was 3.2 foot-candles (34.5 meter-candles), but that when the intensity fell below this point, it became necessary to supplement the daylight by artificial light. The low intensity of daylight required for the work points to the conclusion that with a modified design of the system of artificial lighting, even a lower intensity of illumination than that which now obtains in the remodeled installation in this factory, would suffice.

Stress is laid on this illustration to point out the limitations of any broad statement to the effect that a specified intensity of illumination is needed for one class of work, and another intensity of illumination for another class.

* From "Factory Lighting: Design of Illumination of a Weaving Room," by L. B. Marks. The Illuminating Engineer, February, 1910, p. 639, March, 1910, p. 39.

It may be noted also that the required intensity will depend upon the "personal equation" of the user. An intensity that is satisfactory to one user may not be satisfactory to another.

Intensity of Artificial Illumination Compared with Daylight. It has just been pointed out that in one instance the intensity of daylight required for a certain class of work, under the specific conditions that obtained in the interior alluded to, was 3.2 foot-candles (34.5 meter-candles), whereas with one system of artificial illumination in this interior, the intensity required was from 4 to 6 foot-candles (43 to 64.5 meter-candles), and with another about 20 foot-candles (215 meter-candles).

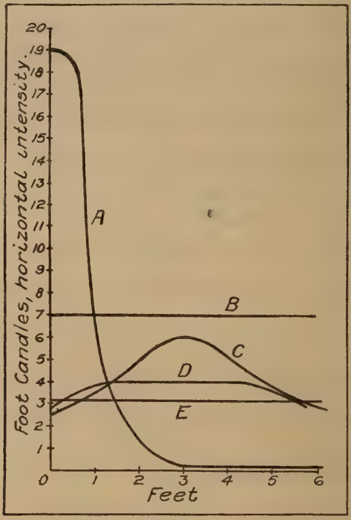


FIG. 14.—Curves Showing Intensity of Illumination on a Loom 6 Feet Long.

A. Artificial light, drop-lamps (strictly localized lighting).
B. Daylight, 3 P. M.
C. Artificial light, front of loom (general lighting combined with directed lighting).
D. Ditto, rear of loom.
E. Daylight, 4.55 P. M.; minimum daylight sufficient for the work.

In the case of an office which was illuminated by a cluster of lamps at the ceiling, it was found that an intensity of 2.1 foot-candles (22.6 meter-candles) artificial light was ample for reading fine print with ease in any part of the room. On a very dark, cloudy day, in the same office, it was found that the minimum intensity of daylight on the working spaces was 29 foot-candles (312 meter-candles).

In still another case it was found that with well-diffused artificial light, approximately 6 foot-candles (64.5 meter-candles) intensity, on a vertical plane was required under the conditions that obtained for the particular class of work in hand, whereas in daylight, on a bright day, the actual intensity of natural light on the work was 400 foot-candles (430 meter-candles).*

In another case, in the postal service, it was found that an intensity of 1.6 foot-candles (17.2 meter-candles) daylight illumination was sufficient for the work, and that artificial light was required when the intensity of daylight fell below this value. In this installation an intensity of approximately 1.5 foot-candles (16 meter-candles) artificial light was sufficient.

In a public library it was found that an intensity of daylight of from 100 foot-candles (1076 meter-candles) down to 5 foot-candles (53.5 meter-candles) satisfied the readers, and that 1 foot-candle (10.7 meter-candles) intensity of artificial light satisfied some of the readers, whereas 6 foot-candles (64.5 meter-candles) intensity was not sufficient for others.

Under actual practical conditions in daylight illumination we are able to see well throughout a very wide range of illumination intensities, provided the conditions under which the illumination is carried out are suitable. The actual intensity of illumination *per se,* really plays a comparatively small part in the problem of securing good lighting.

In artificial lighting a "dim religious light" is often sufficient even for reading purposes, though the intensity of illumination on the book may fall considerably below 1 foot-candle (10.7 meter-candles). On the other hand, if artificial light is properly diffused and directed the eye readily adapts itself to illumination intensities within extremely wide limits, and we can read with comfort in an interior in which the actual intensity on the pages of a book exceeds 500 foot-candles (5380 meter-candles).

In daylight, under usual conditions, the eye works with a comparatively small pupillary aperture, because of the enormous flux of light. In artificial lighting, under good conditions of diffusion, direction and contrast, the eye works with a comparatively large pupillary aperture, because of the relatively insignificant flux of light. Under these conditions we can therefore see well, and with-

* See "Factory Lighting," L. B. Marks, Transactions Illuminating Engineering Society, November, 1909, p. 828.

out visual fatigue, by artificial light at illumination intensities that are only a very small fraction of those which ordinarily obtain in daylight.

In daylight the eye is rarely exposed to the primary source of light, whereas in artificial light the primary source is often within the ordinary field of view. Hence the effect of contrast in intensity of the source and intensity of light on objects viewed, enters to a far greater extent in artificial lighting than in daylight.

LECTURE II

C. Systems of Illumination. The various systems of illumination may be broadly classified as follows:

(*1*) General illumination by direct lighting:

(a) Lamps exposed to view.

(b) Lamps enclosed in globes or mounted behind a transmitting screen or septum.

(*2*) General illumination by indirect lighting; primary lighting sources totally concealed from view and illumination carried out entirely by reflected light:

(a) Cove lighting.

(b) Lighting by lamps concealed in opaque reflectors suspended from the ceiling.

(*3*) Local illumination. Lighting carried out entirely by lamps placed to localize the light on the work.

(*4*) General illumination by combination of direct and indirect lighting:

(a) Direct lighting units supplemented by indirect lighting.

(b) Indirect lighting units supplemented by direct lighting.

(c) Combination of direct and indirect lighting in the same unit.

(*5*) Combination of general and local illumination:

(a) General illumination supplemented by localized lighting at places where a higher intensity of illumination is desired.

(b) Local illumination of such design as to provide general illumination.

In the system of general illumination by direct lighting, the lamps are exposed to view or are enclosed in globes, or mounted behind a transmitting screen or septum, such as a diffusing skylight or art-glass panel.

In the system of general illumination by indirect lighting, the lamps are concealed from view, and the illumination derived wholly from reflection of light from the ceiling and walls of the interior, which constitute the indirect or secondary sources of illumination. Indirect lighting is commonly carried out either by means of lamps concealed in coves located on the side walls near the ceiling, or by means of lamps concealed on opaque reflectors suspended from, and pointed toward, the ceiling.

Practically all systems of general illumination by direct lighting may be looked upon as a combination of direct and indirect lighting, as part of the light comes directly from the primary or lighting source, without any reflection, and part from the secondary lighting source, namely, the ceilings and walls, after reflection.

In the above classification, the distinguishing difference between the direct and the so-called indirect system of lighting is, that in the indirect system none of the light from the primary source reaches the floor until after reflection from the ceiling or walls or both.

In the system of local illumination, the lighting is carried out entirely by lamps placed to localize the light on the work. Each table, machine or work-bench, as the case may be, is usually lighted by an individual lamp suspended from the ceiling or mounted on a bracket on the wall, or on a standard. Sometimes the system of local illumination is carried out by group lighting. In the system of strictly localized lighting, the lamps are usually backed by opaque reflectors intended to concentrate the light on the work and at the same time shield the eyes from the direct light of the lamp; the photograph (Fig. 15) brings out strikingly the characteristic lighting with this system.

Various combinations of direct and indirect lighting for general illumination, and of general and local lighting have been named above. In the system of general illumination by direct lighting units with supplemental indirect lighting, the lighting is essentially direct with a background of indirect illumination, whereas in the system of general illumination by indirect lighting units, with supplemental direct lighting, the lighting is essentially indirect.

General illumination, whether direct or partially or wholly indirect, may be combined with local illumination by supplementing the general lighting of an interior by localized lighting at places

where a higher intensity of illumination is desired. General and local illumination are also combined in a system in which the design of the local lighting is such as to distribute a suitable portion of the light flux for general illumination.

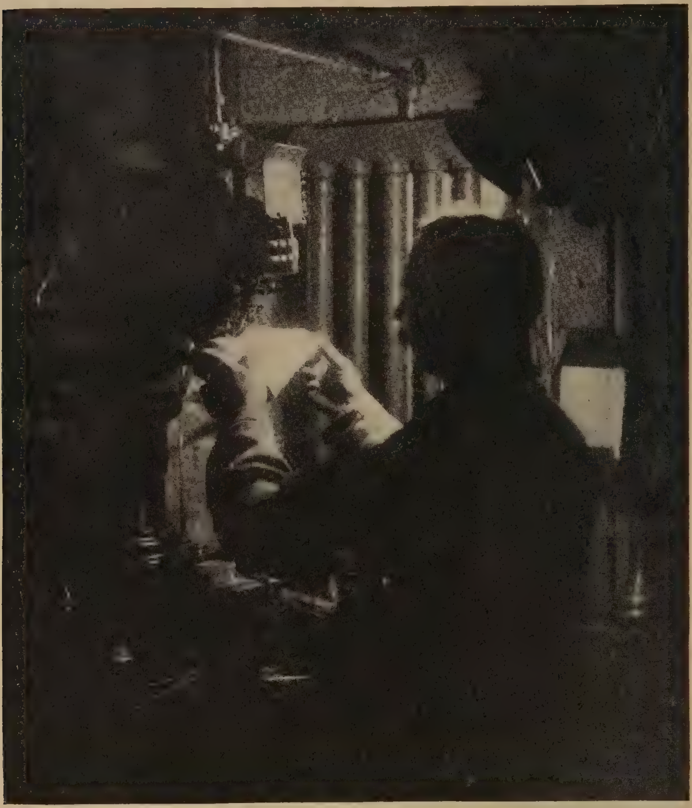


FIG. 15.—Characteristic Illumination with a System of Strictly Localized Lighting.

D. Location of Lighting Sources. Man has been accustomed from time immemorial to daylight illumination from side windows. In locating artificial lighting sources for the illumination of an interior, it would therefore seem logical to reproduce, as nearly as possible, the conditions that obtain in daylight illumination, and to locate the lighting units at or near the windows. If we could obtain a sufficiently large flux of artificial

light without undue expenditure of power, and could distribute this flux in a manner analogous to that of daylight, the problem of locating the lighting units would be a comparatively simple one. With the restrictions with which we now have to contend, and with which we will probably have to contend for all time in supplying a substitute for the sun, we are compelled to so locate our lighting units that the comparatively meager flux of light we are able to obtain from them can be utilized to best advantage to meet the special requirements of the interior with which we have to deal.

In artificial lighting the location of the lighting units will depend upon (a) the use to which the interior is to be put, (b) the system of lighting employed, (c) the character of the illuminant used, (d) the ability to diffuse and direct the light, (e) the removal of the light from the field of view, (f) the avoidance of strong contrasts in illumination, (g) the structural conditions in the building, (h) aesthetic considerations, (i) accessibility, (j) economy.

Before deciding on the location of outlets, it is necessary to know the character of the illuminant to be used. If the vacuum tube, for example, is to be employed for lighting a large room, a single outlet on the ceiling or on the wall might be sufficient, whereas, if tungsten lamps are to be used, several ceiling outlets may be required to suitably distribute the light. If gas is to be used, the limitations in location due to necessary placement at some distance below the ceiling must be taken into consideration.

To determine the position of the lighting units it is necessary to decide on the system of illumination that will be employed to best meet the conditions of usage of the light. If general illumination only is to be used, only ceiling outlets need usually be considered. If local illumination is to be used, or a combination of local and general, the location of outlets for such illumination must be determined.

In a large room in which a moderate degree of illumination meets all the requirements, a lighting fixture centrally located on the ceiling may answer the purpose, whereas, if a very high degree of illumination is needed in some parts of the room, the central lighting fixture might have to be supplemented by local lamps placed more or less close to the objects to be lighted.

The location of the lighting sources will be governed in a mate-

rial degree by the extent to which it is possible to direct or redirect the light of the particular illuminant, by reflectors and diffusers.

The location of the lighting sources should be such as to keep the lamp as far as practicable out of the ordinary field of view, and to avoid violent contrasts in illumination.

Due cognizance must be taken of the structural conditions of a building in locating lighting sources. Sometimes the limitations are such that it is impracticable to place a lamp in any location other than in the center of a bay. Frequently, both from the standpoint of distribution of illumination and from the architectural standpoint, the location of the lighting unit in the center of a room, or in the center of a bay, works out to best advantage.

In deciding on the location of outlets cognizance must be taken of aesthetic considerations. The placement of the lights must be such that the ensemble will look well. In other words, the arrangement of the lighting units must be aesthetically as well as scientifically good. Where it is planned to carry out a certain style of lighting, as by fixtures of the Louis XIV period, for instance, the location of the outlets for the lighting units must be arranged accordingly.

Often the need of accessibility for replacement or for local lighting or extinguishing of lamps is a governing factor in the location of the outlets.

The broad question of economy, not only in the cost of the lighting installation but also in the cost of its maintenance, is often a deciding factor in the location of the lighting sources. Although far better results in illumination may be obtained with one system of illumination than with another, the better system may be proscribed because of too great cost of installation, and too great cost of operation. In such a case, the location of the lighting units must conform to the needs of the less expensive installation.

E. Lighting Fixtures: Globes, Shades and Reflectors. It is not uncommon for architects to provide a certain number of outlets for the lighting of an interior, and to leave the matter of design or selection of the lighting fixtures in abeyance until the building is so far along in construction that the problem of lighting is not one of designing the most suitable lighting ar-

rangements for the interior, but one of designing the most suitable fixtures to fit the limitations which have been imposed in the location of the outlets. In other words, the design of the lighting fixtures is left for after-consideration.

To secure definite predetermined results, it is necessary to know in advance the general decorative scheme and wall coloring of an interior in order that the location of lighting units and the design of the lighting fixtures may be planned with reference to the re-required illumination of the *finished* interior. Without a knowledge of these conditions, the design of the lighting fixtures must be at best a compromise, and the lighting result must depend upon a " cut and try " method. Without the data referred to, the selection of globes, shades and reflectors becomes a matter of guess work rather than of scientific procedure.

F. Glare and Intrinsic Brightness. As a general principle of illumination, the specific brightness of the lighting sources within the field of view should be kept within certain limits. These limits have been variously placed by different authorities at from 4 to 5 candle-power per square inch (0.62 to 0.78 c. p. per sq. cm.) of the lighting source down to from 0.2 to 0.1 of a candle-power per square inch (0.031 to 0.016 c. p. per sq. cm.) of actual surface. This refers to primary lighting sources. The figure for maximum intrinsic brightness per square inch of lighting source cannot, however, be taken as a criterion, unless the dimensions of the source itself be coupled with this figure. The area of the lighting source within the field of view, as well as its specific brightness, must be kept within definite limits under given conditions to avoid eye-strain. No exact data are available as to the safe maximum limits in specific cases, and, indeed, such data, even if secured, would be of little practical value unless all the conditions of usage of the light were stated in connection therewith.

For example, unless the conditions of contrast in illumination are known, the numerical value of the safe limit of intrinsic brightness would mean very little. Thus a specific brightness of 5 candle-power per square inch (0.78 c. p. per sq. cm.) may not produce material eye-strain or visual fatigue if there is not excessive contrast; whereas, on the other hand, a specific brightness of 0.1 of a candle-power per square inch (0.016 c. p. per sq. cm.) may produce considerable eye-strain and visual fatigue if there is excessive contrast.

Referring to the secondary lighting sources, such as the ceiling or walls, as the case may be, the specific brightness, even though numerically very small, becomes a serious matter if a large area of the illuminated surface is continuously within the field of view, as it often must of necessity be. There is need of complete and accurate data along these lines. We have been guided in the past by experience, but little has been done in this connection to formulate a scientific basis for correct illumination design. For example, exact knowledge of this phase of the subject is needed to give us a better insight into the question of the relative merits of direct and indirect lighting.

In connection with lighting installations we must consider, first, the glare of the primary and secondary lighting sources, and, second, the glare of the objects illuminated. In minimizing glare, the location of the lighting sources and their specific brightness and area must be taken into account. This involves the consideration of the diffusion and direction of the light, the contrast in illumination and the regular or specular reflection.

G. Regular or Specular Reflection. The general problem of arranging the lighting sources with reference to the avoidance of regular reflection was considered in discussing the location of lighting units.

When light strikes an object, part of the rays are absorbed by the object, part pass through (in the case of a transparent or translucent object), part are reflected diffusely and part are reflected regularly. The regularly reflected rays are those we are now considering.

The regular reflection from calendered paper of a book may be so trying as to prevent good vision and cause severe eye-strain. Hence, if the position of the eye with respect to the lighting source and the object viewed, is necessarily such that the rays that strike the object are directly reflected into the eye, the lighting is defective. If work is done at an ordinary polished oak table located in the center of a room, illuminated by a lamp directly above at the ceiling, the specular reflection from the surface of the table will be very trying to the eye unless the observer is seated in such a position that the direct reflected rays do not strike the eye. Unless the table is a long one, it will be impossible to escape a considerable percentage of the regularly reflected rays. In such a case, under practical conditions, the use of an exposed lamp at

the ceiling, even if the lamp be frosted and backed by a diffusing reflector, is almost prohibitive. To reduce the amount of regular reflection to a tolerable degree the lamp must be screened by a diffusing globe of considerable area and low specific brightness.

In practice, we find on all sides serious results from the direct reflection of light from objects viewed; be it in the library of a palatial residence in which the library table is fitted with a polished plate-glass top, or in a factory in which the workmen handle highly polished pieces in the assembling of apparatus or face highly polished portions of machines, the baneful influence of regular reflection may be noted. In many cases the excessive regular reflection is due to faulty illuminating engineering.

In one instance in actual practice it was found in a factory that the direct reflected light which reached the eyes of an operator who was at work on polished material was almost 40 per cent of the light which reached the object viewed. When this direct reflection was cut down by a change in the installation, the operator could see the work much better and with much less visual fatigue.

H. Contrast. It has been stated that in planning the artificial illumination of an interior, the diffusion and direction of light should be such as to avoid striking contrasts in illumination in different parts of the interior. There is, perhaps, no single item that comes up in the consideration of a lighting scheme that is of more importance, from a physiological standpoint, than that of contrast. This factor has already been considered in discussing the different systems of carrying out illumination and the requisite intensity of illumination for specific kinds of work. We may consider the subject of contrast under two divisions, (a) contrast in intensity or character of illumination in different parts of the same room or space, and (b) contrast in the illumination of two contiguous rooms or spaces.

If an observer passes directly from one interior in which the illumination is of a high order to a contiguous interior in which the illumination is of a low order, the intensity of illumination in the second interior may strike him as being insufficient. Had the order of the illumination in the one interior been the same as that in the other, even though the illumination in both interiors were less than that of the less brightly lighted one, the observer might have found this reduced intensity of illumination quite sufficient. If, after spending some time in the less brightly lighted

interior, the observer passes to the more brilliantly lighted adjoining room he may deem the latter over-illuminated. These effects are due to contrast in illumination.

An isolated show window, having a moderate intensity of illumination, may admirably set forth the wares displayed therein, but when a neighboring window, having eight or ten times the intensity of illumination of the first, is lighted up the first will appear but dimly lighted, and the owner to give due prominence to his display will be compelled, because of contrast with the neighboring window, to raise the plane of his illumination.

Actual measurements show that largely because of this principle of contrast the plane of illumination in stores, public buildings, places of amusement, and even residences, has been carried much higher in some cities than in others, and abnormally high in some sections of the same city. For example, the plane of illumination in the leading stores, especially the department stores in New York City, has gradually been raised from 1 to 2 foot-candles (10 to 20 meter-candles) to 4 to 6 foot-candles (40 to 60 meter-candles). A part of this rise may be accounted for by the comparatively recent introduction of high-efficiency lamps, such as the tungsten, mantle burner and other types, but the most potent factor underlying this increase in intensity is undoubtedly the principle of contrast. When your neighbors' stores are brightly lighted you are compelled in self-defense to light your own place brightly because of the contrast. When your streets and public spaces are more brightly lighted you are compelled to light your homes more brightly because of the contrast.

Considering now the question of contrast in different parts of the same room, we have an analogous condition to that just discussed. If one part of a room is extremely bright and another part extremely dark, the bright part appears brighter by contrast, and the dark part darker. If these contrasts are extreme, the eye receives a shock more or less violent in glancing from one part of the room to another, and if, as may happen when several people in conversation are seated around a room illuminated in this way, one frequently looks alternately from a dark section to a light section of the room the eye is soon severely taxed. If, however, the conditions of contrast are only very moderate, the eye may actually be rested by glancing from the brighter objects to the darker objects in a room.

If brightly lighted walls or ceiling be within the ordinary field of view, the discernment of objects in the room or of the printed matter on the page of a book on which the illumination intensity is less than that of the walls and ceiling, will be far more difficult than if the illumination intensity on the objects viewed were greater than that of the walls and ceiling within the field of view.

A common example of lighting, in which the evil effects of violent contrast are strikingly exhibited, is the illumination of a moderately large dining room in which the walls are very dark in color, and the illumination carried out exclusively by a central dome fixture, approximately 2 feet (61 cm.) above the table, the fixture being equipped with two or three 16-candle-power incandescent lamps within the dome, which latter is constructed of slightly translucent art glass. The table is brilliantly illuminated, the intensity on the table-cloth being not infrequently from 8 to 10 foot-candles (80 to 100 meter-candles). In looking across the table to the person seated opposite, one looks through a field of great brightness at the table into one of almost dense blackness at the walls. It need hardly be stated that this violent contrast is conducive to eye-strain.

I. Shadows. We are so accustomed to the natural shadows that occur in daylight that we rarely notice them, yet these shadows are absolutely necessary to bring out the form and perspective of objects viewed. When we attempt, however, to imitate in artificial lighting, the conditions that obtain in daylight illumination, we find that unless the character of the artificial lighting is such as to produce effects of light and shade somewhat similar to those that obtain in daylight, we are apt to fall far short of the realization of good illumination.

Steinmetz * has discussed the importance of the subject of shadow in illuminating engineering substantially as follows:

Objects are seen by differences in color and in intensity, or brightness; for producing differences in intensity shadow is of great assistance, and, indeed, the differences of intensity by which objects are seen are, to a large extent, those due to shadows. If the illumination were perfectly diffused and no shadows produced,

* C. P. Steinmetz, "Illumination and Illuminating Engineering," Trans. I. E. S., January, 1910.

then, even if the intensity of illumination were sufficient, the illumination would be unsatisfactory in most cases of lighting, because of the loss of the assistance of the shadows in distinguishing objects. Seeing under such conditions would become more difficult, and the effect of the illumination would be uncomfortable.

The use of shadows for illumination requires directed light, that is, light coming from one or a number of sources, and not merely diffused illumination coming from all directions. However, it is not sufficient to provide directed lighting only.

For satisfactory illumination, it is necessary to have sufficient directed light to mark the edge of the objects by their shadow and thereby improve the distinction, but at the same time there must be sufficient diffused light to see clearly in the shadows; that is to say, a proper proportion of directed and diffused light is necessary.

In cases in which all the objects assume practically the same color, such as in flour mills or foundries, a diffused illumination without shadows would make the illumination so bad as to be practically useless. In a drafting room, on the other hand, where all of the objects requiring distinction are in one plane, and the distinction is exclusively by differences of color and intensity, but not by shadows, a perfectly diffused illumination is required, and noticeable shadows would be objectionable.

The purpose of the shadow in illumination is to mark the edge of the object, and to show its height by the length of the shadow. The shadow, therefore, should not extend too far from the object to which it is related, otherwise it loses its close relation to it and becomes misleading, and therefore interferes with good illumination. Hence the directed light should come from above in a direction making a considerable angle with the horizontal, so as to limit the length of the shadow, but the light should not, however, come vertically downwards, as this direction would largely obliterate shadows.

In the use of shadows in illuminating engineering it is necessary for the outer edge of the shadow to blur or gradually to fade, and this result requires that the source of directed light should not be small, but should be sufficiently large to scatter the light at the outer edge of the shadow. This requirement necessitates the use of a diffusing globe or its equivalent so as to have the light issue from a fairly large luminous area.

J. Aesthetic Considerations. Some one has stated that no design of illumination is physiologically correct unless it is aesthetically good. However this may be, there is no question as to the importance of aesthetic considerations in planning the artificial lighting of an interior.

The mere delivery of a definite number of foot-candles on a working plane is only a small part of the performance which the illuminating engineer must exact of his tools; indeed, this feature of the illuminating design may often be relegated to an entirely subordinate place. In purely utilitarian lighting, as in factories, the aesthetic feature of the design naturally does not play as important a part in the design as in the home, the library, the theater, etc.; but even in the factory, where up to the present aesthetic considerations have been to a large extent ignored, there is reason to expect that it will actually pay to devote more attention to this phase of the subject. The eye craves the beautiful, whether it be in the salon or in the workshop.

A lighting fixture that is not in harmony with its surroundings is a fixture out of place even if it gives adequate illumination. Illumination that does not give suitable color, and suitable light and shade effects, is aesthetically wrong, and therefore defective.

K. Economy and Efficiency. In planning a system of illumination, the question of economy in first cost and economy of upkeep may be a governing consideration. In fact the initial cost of the lighting equipment is commonly a limitation that is placed upon the design of the illumination. The practical problem usually is not, "What system of lighting will give the best illumination?" but "What is the best system of lighting that can be installed within the specified limit of cost?"

A mass of data has been published on the cost of illuminating interiors by different classes and types of illuminants and by different systems of illumination, but these data are very incomplete in that they do not fully set forth all of the conditions that obtain in the lighting in each case. Usually the criterion in these data is the "effective" lumens per watt of electric power expended or per cubic foot of gas consumed.

As has been previously stated, this value is not necessarily a criterion, and, indeed, is often far from being a criterion of the real, that is, the *ultimate* economy of lighting. No matter what

the "effective" lumens on an assumed working plane may be or whether these lumens are produced by illuminants, the first cost of which and the cost of the upkeep of which is less than that of any other, the lighting, broadly speaking, is uneconomical if the result of the illumination is physiologically bad.

The switching arrangements constitute an important feature in the economy of use of light. Economy is furthered (a) by the facility with which lamps may be lighted or extinguished, and (b) by the separate control of individual lamps or groups of lamps. Thus, for example, if the control of a lamp or lamps is conveniently located, the user will be more apt to extinguish the lamp that is periodically used during the day than he would be if the control were remote. Again, if the natural light at the further end of a room is insufficient in waning daylight, while the light near the windows is sufficient, the user may economize in lighting if the lamps at the windows are grouped under separate control, thus permitting the lighting of lamps in the darker portions independently. Similarly, in large interiors, the separate control of a pilot-lighting circuit that is intended to give only a very moderate illumination after hours of regular use, for cleaning purposes and the like, often results in considerable economy of lighting. Even in the dining room of the residence the separate control of a lamp of small candle-power, giving just sufficient light for setting the table, is a factor in the economy of lighting.

Efficiency of Illumination

In illuminating work, starting with the illuminant, we have three efficiencies to consider: (a) the efficiency of the lamp, that is, the lumens generated by the lamp per watt of electric power expended in the lamp or per cubic foot of gas consumed; (b) the *gross* efficiency of the illuminating installation, that is, the lumens effective on a reference plane per watt of electric power expended or per cubic foot of gas consumed; and (c) the *net* efficiency of the illuminating installation, that is, the lumens effective on a reference plane per lumen generated. The net efficiency may be stated to be the efficiency of utilization of the light.

While the ratio of lumens delivered on the reference plane, to lumens generated, is a measure of the efficiency of utilization, this ratio is, of course, not to be taken as a complete measure of the

illuminating result. The illuminating result will be affected by the specific brightness and area of the primary and secondary lighting sources within the field of view, the contrast in intensity of illumination on walls, ceiling, floor and objects in the room, etc. As an illustration of this point it may be stated that if an indirect lighting unit designed to throw all the light to the ceiling, were converted into a direct lighting unit by simply turning the unit upside down, the lumens delivered on the working plane might, in a specific case, be 100 per cent greater than when the lamp and reflector are turned toward the ceiling. The efficiency of utilization in the former case may be twice that of the indirect lighting unit, but the illuminating result, if it could be expressed in terms of ability to see on the reference plane, might nevertheless be decidedly in favor of the indirect lighting unit.

In practice it is found that we may have the very worst lighting in cases in which the largest percentage of the total flux of light generated by the lamps is delivered to the working plane. Take, for example, a living room 20 feet (6 m.) long by 15 feet (4.5 m.) wide and 10 feet (3 m.) high, with dark-colored walls, the lighting of which is carried out by a single lamp in the center of the ceiling, the lamp being housed in a deep opaque-mirrored reflector of such design as to throw the maximum light on the working plane, 2 feet 6 inches (91 cm.) above the floor. In this case no light goes directly to the ceiling or upper portions of the walls. Such a lighting design would be atrocious from the standpoint of desirable illumination, even though an extremely large percentage of the total flux of light from the lamp were delivered on the working plane. The contrast effect in illumination would be so great that under normal conditions of usage of the room the eye would quickly become fatigued.

Comparison of Direct and Indirect Lighting

The greatly increased efficiency of lighting made possible by the introduction of improved electric and gas illuminants has led to the further development of indirect systems of illumination, both electric and gas, and has brought to the foreground the discussion of the merits and shortcomings of this method of lighting.

In the system of illumination known as "indirect lighting," the primary lighting source is concealed from view, and the illumination from it derived wholly from reflected light from the

ceiling and walls, which become the secondary lighting sources. Indirect lighting may be carried out by lighting sources disposed in a cove or coves located near the ceiling, at the sides of a room or in the central portion of a room.

Another method of indirect lighting which has come into more or less prominence within the past year or two is carried out by lighting units hung from the ceiling, the lamps being concealed from view by an opaque backing. This is the system to which the following discussion, for the most part, relates. In carrying out this system the lamps are backed by powerful reflectors pointed toward the ceiling. Usually the lamp and its reflector are contained in an opaque basket or bowl. The lighting unit may consist of a single lamp and reflector or of a number of lamps and reflectors all mounted in the same housing.

The intent of the design of this system of lighting is to totally conceal the primary lighting source from view, and to throw as large a percentage of the total flux of light as possible directly to the ceiling. To make the system effective from the standpoint of illumination delivered on the working plane, light-colored ceilings are required.

Where it is desired to confine the flux of light within a small area of the ceiling a concentrating reflector is used, and where a wider distribution is desired a distributing reflector is used. It has been found in practice, however, that the distance of the lighting unit from the ceiling and the distribution of flux of light may be varied within comparatively wide limits without materially altering the numerical value of the illumination intensity on the working plane.

It will be seen that the efficiency of utilization of light is greater when the illumination is carried out by this method of indirect lighting than would be the case in ordinary indirect lighting by coves, because with ordinary cove lighting the bulk of light from the lamps suffers at least two reflections, one from the ceiling and one from the walls, before it reaches the working plane; whereas, with the method under discussion the bulk of the light reaches the working plane after only one reflection—from the ceiling. With a single reflection from the ceiling, the loss is estimated in the case of light ceilings not to exceed about 40 per cent of the light reaching the ceiling. In the case of an additional reflection from the walls (assuming the walls to have the same coefficient of reflection

as the ceiling) the light reflected from the ceiling to the walls would suffer another loss of about 40 per cent. If the walls are dark in color this second loss might easily amount to 85 or even 90 per cent.

While it is true that in the earlier forms of cove lighting the design was such that a large part of the light from the lamps in the cove suffered multiple reflections before reaching the working plane, coves may be so designed that the bulk of the light will be directed to the ceiling at such an angle as to suffer only one reflection. Moreover, any desired angle of reflection of light from the ceiling may be secured by suitably designing the cove. A cove of this character was designed and installed in 1907, in the library and assembly room of the Edison Electric Illuminating Company, Boston, Mass. The description and performance of this lighting installation are recorded in the Transactions of the Illuminating Engineering Society.*

The most important point to consider in evaluating the claims of any system of lighting is, in the last analysis, the physiological effect of the lighting.

With respect to the relative brightness of ceiling, walls and floor, we have, with the indirect lighting system, a partial inversion of the conditions that obtain in daylight illumination. With the indirect system of lighting the ceiling is the brightest portion of the room; whereas, in daylight illumination, the floor receives the maximum flux of light.

In general, we have a directive side illumination in daylight; the light entering the interior through windows at the sides is diffused throughout the room. This diffusion does not mean that the illumination is shadowless. On the contrary, owing to the direction of the light, the objects in the room cast more or less shadow. This shadow is of great importance in distinguishing objects clearly and in giving proper perspective.

In the system of indirect lighting by suspended lighting units backed by opaque reflectors, the ceiling becomes the secondary lighting source from which the entire illumination of the room must be derived. The natural result of illumination of this character is, that the side-shadow is either absent or very faint. This con-

* "Lighting of the Edison Building," by Louis Bell, L. B. Marks and W. D'A. Ryan. Transactions I. E. S., October, 1907.

dition is in striking contrast with that which obtains ordinarily in the daylight illumination of interiors.

In considering the physiological effect of lighting by indirect illumination, the proportions of the interior, as well as the use to which the interior is to be put, must be taken into consideration. For example, in a room with a very high ceiling, where the ceiling is not within the ordinary field of vision, a relatively high specific brightness of the ceiling may not be objectionable, while, on the other hand, in an interior in which the ceiling is either always or for a large part of the time, within the ordinary field of vision of those occupying the room, the brightness of the ceiling and side walls have an important bearing on the ability to see well.

The visibility of objects depends upon a number of conditions which have already been discussed. Fundamentally, one of the most important conditions is to have a greater intensity of light on the object viewed than on the ceiling or other portions of the interior that do not require fine discernment.

A very high intensity of illumination on the ceiling and walls, when these are within the ordinary field of view, operates to decrease the visual sensibility mainly for two reasons:

(1) Because a large surface of relatively great brightness within the field of view *per se* reduces the ability of the eye to discern darker objects on the working plane, and

(2) Because the strong contrast in brightness of the ceiling and walls, and that of objects in the room, renders it more difficult to distinguish details of the objects viewed. Dark-colored objects in a room appear all the darker when the ceiling and upper portions of the room are brighter.

As an illustration of the points above raised, let us take the case of a library in the home. In daylight, in the average library, the intensity of illumination on the ceiling is small compared with the intensity of illumination on the pages of a book in the hands of a reader. In order that the walls may not constitute a secondary lighting source of relatively high brightness, they are usually finished in green or other moderately dark color which will absorb a large percentage of the light incident thereon. The reader is, therefore, not subjected to the visual strain which is incident to having a relatively bright secondary lighting source within the field of view, and his ability to read with comfort is not reduced by the contrast effect produced by a condition in which the ceiling and walls are brighter than the pages of the book.

In reading, it is desirable to rest the eyes occasionally. If, in glancing away from the book, the eye cannot escape the relatively bright ceiling or walls, fatigue of the eye sets in much sooner than when the specific brightness of the ceiling and walls is of a low order. In conversing with people seated on the opposite side of the room, the same holds true. If the general direction of the light is directly downward, as is the tendency in the indirect lighting system under discussion, the absence of shadow, or the unnatural position of the shadow, is trying to the eye.

In the case of a very large room illuminated by indirect lighting, the effect of the downward light is very noticeable. In such a case the directive value of the light reflected from the side walls is minimized. The eyebrow of a person standing in such a room casts a comparatively strong shadow downward on the face, with the result that the features of a person may not be clearly distinguishable except at rather short range. This condition is in striking contrast to that which obtains in the same room in daylight, when the lighting of the room is carried out by side windows. To partially offset the downward shadows, the floor of the room might be finished in a light tint for the purpose of redirecting the light upward by reflection. Obviously, however, such a procedure, even if otherwise practicable, would introduce an even more serious difficulty, as the light reflected from the floor, coming from an unnatural direction, would produce visual fatigue.

In considering the effect of light upon the eye, cognizance must be taken not only of the specific brightness of the primary or secondary lighting sources within the field of view, but also of the area of these sources. It has been demonstrated that of two lighting sources having the same specific brightness, that source which has the greater area exposed to the eye will produce the greater glare.

Absolute uniformity of illumination is desirable only in a few instances in practice. With rare exceptions, a variation in the intensity of illumination in different parts of a room is desirable. Take, as an example, an extreme case in which an object is illuminated equally in all directions. An object so illuminated loses form and detail when viewed.

Millar * found in an experimental installation, that, based on

* P. S. Millar, The Elements of Inefficiency in Diffused Lighting Systems. Trans. I. E. S., Vol. II, 1907, p. 590.

an average of ten observers, the intensity of illumination required for reading with indirect lighting was 65 per cent higher than with direct lighting. He states, however, that the conditions of the installation were such that the increase in intensity required for reading with indirect lighting was probably larger than may be considered a representative value. He found further that if a placard was viewed at a distance of 8 or 10 feet (2.5 to 3 m.) thirty times as much light was required to enable an observer to read it as well with the indirect lighting as with the direct lighting arrangement. In this test large portions of the walls were within the angle of vision, and exercised a powerful influence upon the eyes of the observer with both lighting systems. With the direct lighting system the walls were relatively dark, influencing the pupillary action of the eye so that a low intensity upon the placard appeared satisfactory. With the indirect lighting system they were brilliantly illuminated, and so affected the eye that a very intense illumination was required upon the placard.

Millar draws these conclusions from the tests:

"In indirect lighting systems of the class considered, where the illumination of a working plane is one of the prime objects, a large proportion of the light is lost; that which is not lost becomes less effective; brilliant illumination is produced where it is useless and even undesirable; and conditions are established which create a demand for an unduly high intensity of illumination on objects viewed. These effects are present in varying degree in all systems in which control of any large proportion of the light is lost. Among such are cove lighting, lighting with skylight effects, tube lighting, and all systems in which the brilliancy of the light source is reduced by diffusing surfaces used without any directing adjuncts. Lighting with large sources is more liable to these effects than lighting with small sources. The facts indicate the need for devoting as much care to securing suitable minimum intensities, as is generally expended in striving for maximum values. In certain classes of lighting where more light is asked for, the requirements may be served by reducing the intensity of illumination on unimportant objects which are unnecessarily well illuminated. By taking advantage of opportunities to minimize intensities at unimportant places, efficiency is gained, and good lighting as well."

Attention is directed to the fact that the experimental installation on which the tests above recorded were made, is not representative, and does not pretend to be representative, of the best types of lighting installations. It is quite probable that if the lighting units for indirect lighting had been differently disposed in these tests, the results would have been affected accordingly.

For example, if the flux of light from these units had been concentrated on the central portion of the ceiling, instead of broadly distributed over the entire area of the ceiling and upper side walls, as in the tests, the brightness of the walls would not have exercised such a powerful influence upon the eyes of the observer; in fact, if the walls had been dark in color, the relative values for direct and indirect lighting would undoubtedly have been materially modified.

There is need of an exhaustive study of this problem, especially in view of the fact that in modern lighting there is a tendency to go from one extreme to the other, that is to say, to illuminate directly by brilliant exposed lamps, or to illuminate indirectly by totally concealed lamps.

The rapidly growing number of installations in which the indirect system of lighting is carried out, is proof that there is a demand for this kind of lighting. The elements that create this demand need to be carefully investigated.

Mr. J. R. Cravath, in a report of tests of indirect lighting,* calls attention to some essential points to be borne in mind in the application of indirect lighting from suspended chandeliers.. He states that the efficiency of such a system will depend largely on the proportion of the light which is reflected directly from the ceiling to the working plane. He advocates the system of indirect lighting by central chandeliers, in which system the lamps are backed by opaque-mirrored reflectors, and the illumination obtained by reflection from comparatively limited areas of the ceiling. Comparing the effectiveness of direct and of indirect lighting he comments as follows:

"We all recognize that illumination is more a physiological problem than a physical one. Foot-candle values are worthless unless the lighting equipment is so arranged as to unable us to see objects with the greatest comfort consistent with the wattage used. Many arguments both for and against indirect illumination have been advanced which have been based largely on opinions or prejudices not justified by investigation, experience or scientific research. All will probably agree that a sufficiency of diffused daylight is likely to be more satisfactory than any artificial lighting system that we are likely to devise for many years to come. Where this is not true, it is usually because of the insufficiency of the daylight. The first question to be asked regarding any system of lighting is, therefore, as to how nearly it approaches

* Some Notes and Tests on Indirect Illumination. J. R. Cravath. Trans. I. E. S., April, 1909, p. 290.

daylight in its effects. The illumination produced by a system of indirect lighting like that upon which these tests were made may be compared to that received by daylight from a rather dense skylight. It differs from such daylight mainly in intensity and color. The general diffusion and shadow effects are much the same. It differs from daylight received through windows mainly in the angle at which light is received and in its intensity and color. In our so-called direct-lighting systems we really have a combination of direct lighting and indirect lighting, part of the light being received direct from the source and part by reflection from ceilings and walls. Direct lighting differs from the indirect lighting scheme under discussion in that the shadows produced by the direct, are much sharper. In this way the direct is somewhat like direct sunlight, but it certainly is not like diffused daylight as received through a window or skylight. Both diffused daylight and the indirect system under discussion produce shadows, but they are not marked."

Mr. Cravath reports that the specific consumption of electric power in the above tests of indirect lighting was as follows:

	Watts per effective lumen
Light-colored ceiling and walls..................	0.35
Light-colored ceilings and dark walls............	0.45

From the data of the tests it appears that the net efficiency, that is, the ratio of the lumens effective, to the total lumens generated, was approximately 36 per cent for light-colored walls and 28 per cent for dark-colored walls. Compared with commercial systems of direct lighting employing efficient reflectors, the above values indicate that for the same type and candle-power of lamp, the indirect system requires, in general, at least 50 to 75 per cent more power for equivalent effective illumination than the direct system. The effective illumination referred to above, is taken as the mean illumination on a horizontal plane 2 feet 6 inches (91 cm.) above the floor. The figures given refer to new lighting installations, with clean lamps and reflectors. As the lamps and reflectors of the indirect lighting system point toward the ceiling, the more rapid deterioration due to dust must be considered in comparing the "working" efficiency with that of the direct system.

In an elaborate series of tests made in 1907 for the Association of Edison Illuminating Companies, Sharp and Millar * present

* Paper on "Experimental Data on Illuminating Values." C. H. Sharp and P. S. Millar. Read at meeting of Association of Edison Illuminating Companies, September 10, 1907.

photometric data, illumination values and efficiency values for a variety of illuminating installations, including direct and indirect lighting.

The tests were made in the auditorium of the New York Edison Company in New York City. The illuminating installations were selected with a view, (1) to bring out the relative illumination efficiencies obtainable with similar illuminants, variously arranged and variously equipped with reflectors, globes, etc., and (2) to give a basis for reliable comparisons of the illuminating efficiencies of illuminants of different types.

Though the results of these tests apply in all strictness only to the room in question, their general value will be manifest. For information as to the specific conditions of the tests, reference must be made to the paper. Space will permit here only of stating in brief a few of the more important results as follows:

For a cove lighting installation with coves located in the usual manner at the sides of the room near the ceiling, the authors found a net efficiency of 23.7 per cent. The lamp installation consisted of incandescent lamps placed 19 inches (48.5 cm.) apart, at right angles to the axis of the cove, and at an angle of 45° to the horizontal. The cove was re-enameled white immediately before the test.

For an exposed-lamp installation, with clear-glass incandescent lamps mounted near the ceiling, the net efficiency was 48.6 per cent as compared with 47 per cent for frosted incandescent lamps. This test is of interest in showing the very slight decrease in net efficiency by the substitution of frosted for clear lamps. The collateral advantages of such a substitution in many cases, are too well known to need comment.

When these lamps were equipped with prismatic-glass reflectors, the net efficiency rose to 73 per cent, and when equipped with opaque silvered reflectors the net efficiency was 89 per cent. The last test is interesting in showing what a large proportion of all the light generated can be thrown on the plane of reference. It should be noted, however, that in evaluating the performance of reflecting devices the effective illumination on the working plane is only one factor and in many cases this factor is relatively unimportant. In a living room, for example, this factor is quite secondary, while in a show window it is all important.

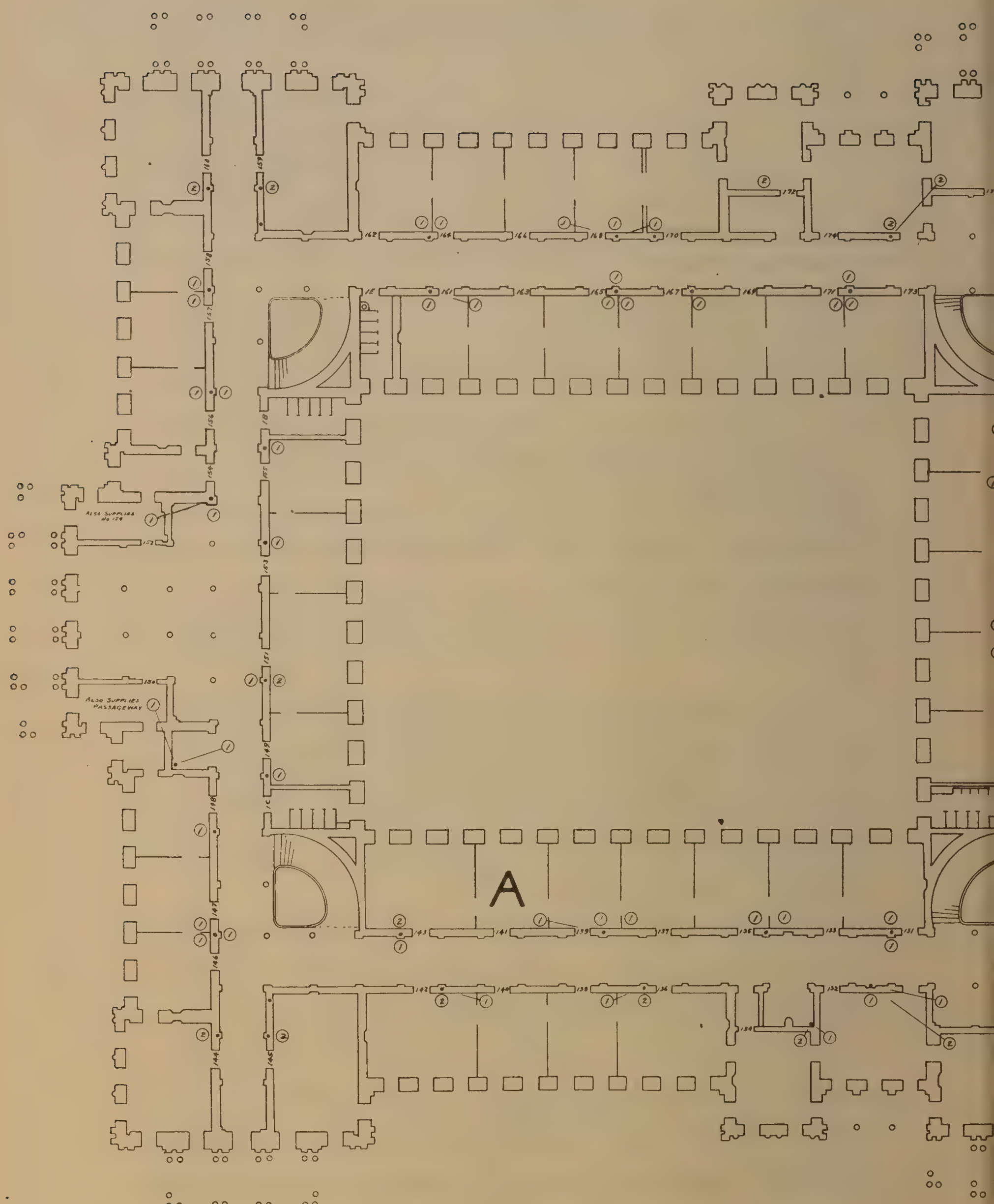
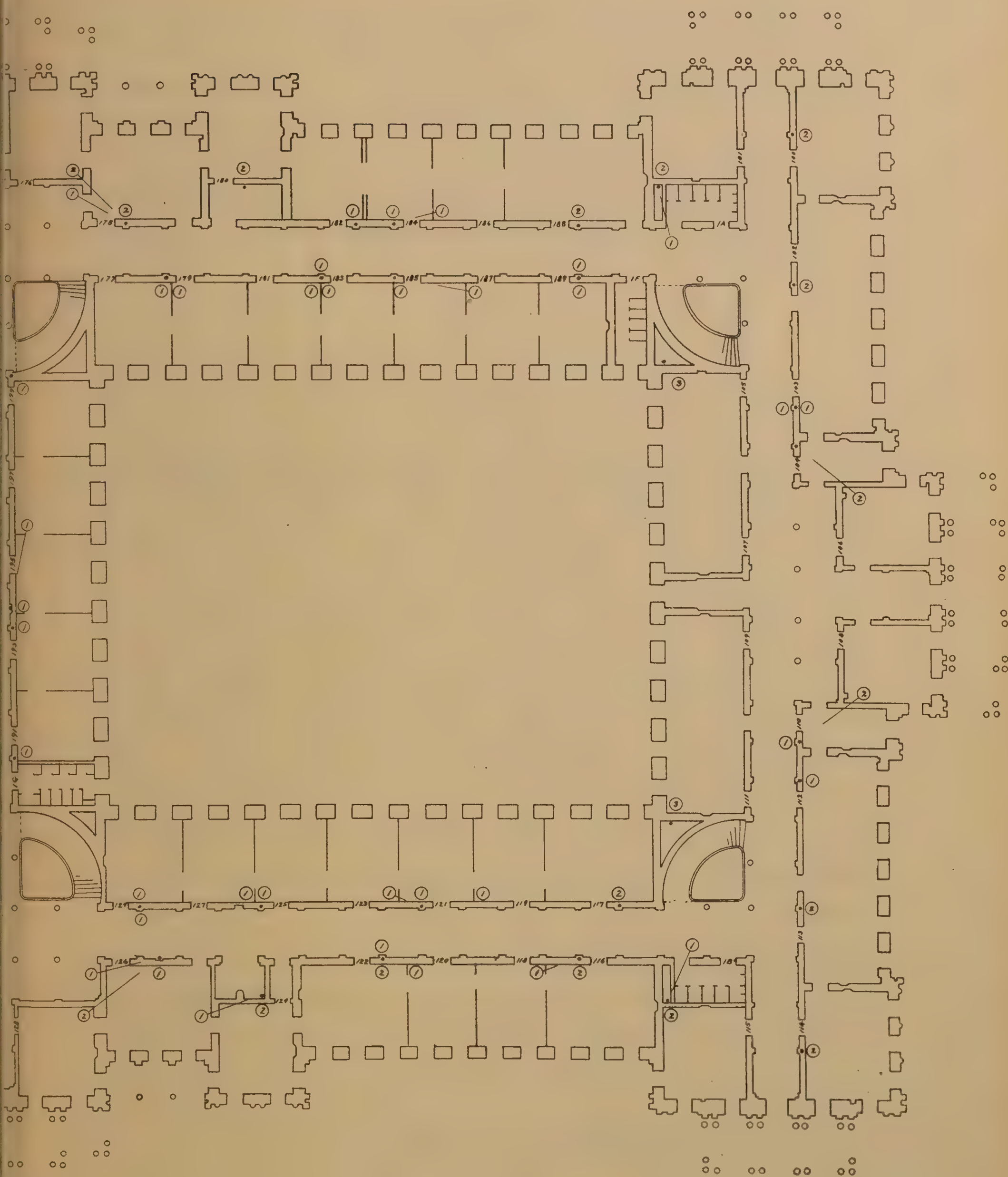


FIG. 16.—Plan of First Floor. State



and Navy Building, Washington, D. C.

Summarizing the efficiency values given above we have, in round figures, the following, all taken for light-colored ceiling and walls:

$$\text{Efficiency of utilization} = \frac{\text{(lumens effective)}}{\text{(lumens generated)}}.$$

1. Indirect lighting: cove lighting......................	20% to 35%
Indirect lighting: lighting units suspended from ceiling.	35%
2. Direct lighting: lamps near ceiling—frosted lamps....	50%
Direct lighting: lamps near ceiling—lamps equipped with efficient reflectors	75%

LECTURE III

Design of Interior Illumination

The limitations of space are such that no attempt will be made herein to cover broadly the application of the principles just set forth. A few typical cases will be taken up for consideration, and the plan of procedure in the design of the illumination in these cases will be discussed, not with the idea of laying down hard and fast rules, which after all might have a very limited application, but rather with the idea of offering a suggestive outline which may be of general value in the design of other lighting installations.

Whether the lighting be for the home, the library or the shop, the same general principles, broadly speaking, must be applied. In the application of these principles each individual case requires special study.

Let us start with the architect's plans of a building in a typical case. Fig. 16 shows a plan of the first floor of the State, War and Navy Building, Washington, D. C. This plan, together with similar plans for other floors, is transmitted to the engineer with the request that he design a system of illumination for the building. The plans give information only as to the general arrangement, size and height of the rooms, corridors, etc., in the building.

In considering the design of the lighting, the first question that naturally suggests itself is, "What is the use to which the building is to be put?" In this case, the building is used largely for office purposes.

As shown on the plan, the first floor space is divided into several rows of rooms, each room being accessible from a corridor. A typical room, marked "A" on the plans, will be considered. The plan and elevation of this room is shown on a larger scale in

Fig. 17. The dimensions of the room are 19 feet 10 inches (6 m.) long by 18 feet (5.5 m.) wide by 16 feet (4.8 m.) high in the clear.

The walls and ceiling are plaster finish, the walls being painted a moderately dark tint and the ceilings, which are arched between beams, are kalsomined white. The trims of the windows and door are painted in a light tint, the door itself being finished in dark

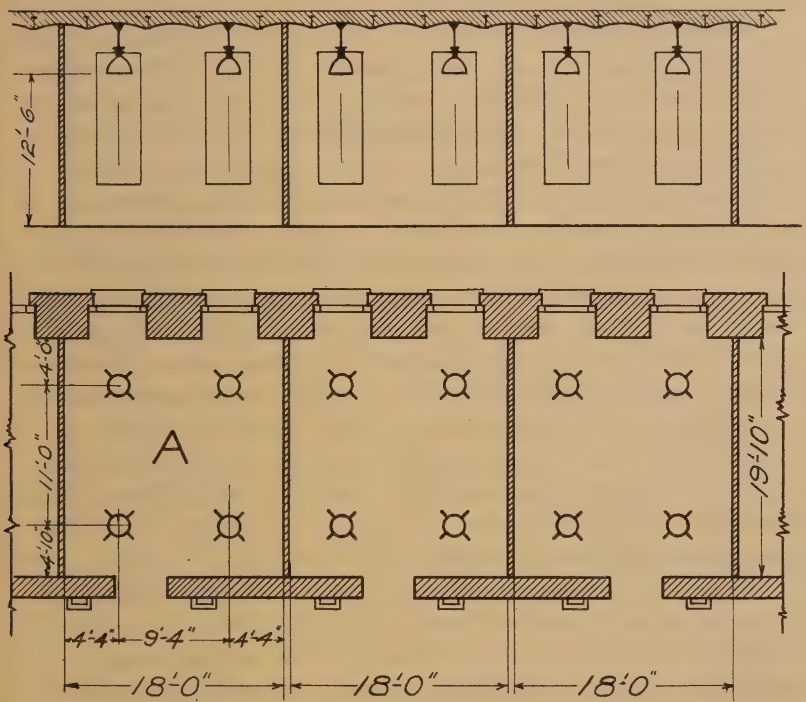


FIG. 17.—Plan and Elevation. Typical Room A. State, War and Navy Building, Washington, D. C.

mahogany. The room is equipped with black walnut and mahogany file cases extending on two or more sides to a height of 8 feet to 12 feet (2.5 m. to 3.6 m.). Some of the rooms are furnished with a double flat-top desk in the center of the room, and one or more typewriter desks in various locations. Other rooms have two or more roll-top or flat-top desks arranged one in each window bay, and one or more additional tables or desks for clerks. Some of the rooms have high-standing bookkeepers' desks.

The regular office work in these rooms is conducted between the

hours of 9 a. m. and 4.30 p. m., with occasional overtime and evening work. The main work is of general office character, including clerical work, typewriting, bookkeeping, making transcripts from records and examining and filing documents.

In considering a design of a lighting installation to best meet the requirements in this case, let us revert to the fundamental principles laid down in Lectures I and II.

A. Selection of the Illuminant. It is specified by the owner that electricity should be used for lighting throughout. The selection of the tungsten incandescent lamp in this instance meets all the requirements set forth under the subheadings (a) to (h), inclusive.

B. Intensity of Illumination. In determining the intensity of illumination required, we must resort to *experience factors,* but in so doing great care must be taken to make due allowance for all differences between the installation which is being planned and similar installations for which we have the experience factors. We must also take into account the "personal equation" of those who use the light. For the installation under discussion, a somewhat higher intensity of illumination is planned than might otherwise be needed, as the artificial light is used for the most part, only during the hour of waning daylight. At this time of day, artificial illumination is used to supplement daylight; under these conditions we find by experience that a higher intensity of artificial light is required than at night.

The actual working space in the room is somewhat less than might be inferred from the examination of the floor plan, as there is considerable furniture located at the sides of the room. It is planned to have an illumination intensity of substantially 3 foot-candles (32.3 meter-candles) on the working spaces. As previously pointed out, stress is not laid on the numerical value of the foot-candle intensity, except in connection with the fulfillment of the requirements set forth in Lecture I, Principles of Artificial Illumination, Section 2 and Headings C to I, inclusive.

Power Consumption. The wattage required to produce an intensity of substantially 3 foot-candles (32.3 meter-candles) on the working spaces in a room of this character, with tungsten lamps located near the ceiling and equipped with the reflectors hereinafter specified, is estimated from experience factors to be approximately 1 watt per square foot (10.76 watts per sq. m.) of floor space. The floor area is 360 square feet. Therefore, the total

wattage required is 360. If four similar units are used in a room, as planned, the nearest commercial size of unit available would be the 100-watt lamp.

C. System of Illumination. Referring to the classification of systems of illumination given in Lecture II, in which these systems are broadly classified under five headings, it is submitted that the particular needs in this case will be best met by system (1)—general illumination by direct lighting. A strictly local system, such as has heretofore been used in the building under discussion, is found to be objectionable, first, because of the large number of individual spaces that require a moderately high intensity of illumination; second, because of the frequent shifting of desks, furniture, etc., in the rooms; third, because of the incidental deterioration and lamp breakage due to handling or tampering with the lamps; fourth, because of the increased regular or specular reflection from local lamps; fifth, because of the strong contrasts in illumination in the room.

D. Location of Lighting Sources. Having planned to secure an intensity of substantially 3 foot-candles (32.3 meter-candles) on the working spaces, it now remains to so locate the lighting units that the total flux of light will be suitably distributed.

Let us assume, first, that only a central lighting unit were used. While it is true that in this case a design might be worked out to distribute the light fairly evenly on the working spaces, such a disposition of the lighting source would not meet the situation for the reason that the light would cast objectionable shadows on the work of some of those seated at tables or desks at the sides of the room. To avoid these shadows, and, at the same time, to distribute the flux of light to best advantage, it is desirable in this case to provide at least four ceiling outlets located near the corners, as shown in the plan. Such a location would conform to the requirements of sections (d), (e), (f) and (g), under the heading of "D," Lecture II, and would also insure the adequate illumination of the high-standing wall cases.

E. Lighting Fixtures: Globes, Shades and Reflectors. With lamps located near the ceiling, as in this case, suitable reflectors must be provided for directing a large proportion of the light downward within a definite and limited zone, at the same time permitting a portion of the light to issue upwards and sidewards for the moderate illumination of the ceiling and upper portions of the

walls. To meet these conditions translucent reflectors of the intensive type are used.

F, G, H, I, J and K. With regard to glare and intrinsic brightness, as the lighting sources are not within the visual angle, the eye is not exposed to the glare of the lamps themselves.

If the lighting units were disposed within the field of view, as, for example, on wall brackets 6 or 7 feet (1.8 to 2.1 m.) above the floor, it would be necessary to materially reduce the specific brightness of the sources. Even with lamps at the ceiling, out of the field of view, the specific brightness must be kept within the lowest practicable limit, as the glare due to regular or specular reflection from polished surfaces of wall cases, articles in the room, etc., may be very objectionable if the specific brightness of the source be high.

In the design under consideration, the effect of specular reflection is very much less than with a local system of lighting in which the lamps are placed close to the work. Moreover, the distribution of illumination in the proposed design is such that striking contrasts in the intensity of illumination in different parts of the room are avoided. Furthermore, with the lighting plan proposed there will be no striking contrast in the intensity of illumination of the various rooms on the floor; this fact has an important bearing in the present instance, as the employees have occasion in the course of their work to pass from one room to another.

The precautions taken to avoid objectionable shadows have already been discussed under heading D.

To secure economy of lighting, the switch-control is such as to permit of the use of a single lamp in the room.

Distribution of Illumination. In Fig. 18 is represented the intensity of direct illumination on a reference plane 2 feet 6 inches (91 cm.) above the floor, with four 100-watt bowl-frosted tungsten lamps equipped with intensive prismatic reflectors. The distribution of illumination is calculated from the polar candle-power curves of the lighting unit, which are assumed to be known. The lamps are numbered 1, 2, 3 and 4. One of the distribution curves shows the mean foot-candle intensity due to the four lamps, on all points along a diagonal of the room; another curve shows the foot-candle intensity at all points on a line passing through the center of the room and parallel to the side walls; and a third curve shows the foot-candle intensity due to one lamp only (lamp No. 3) on

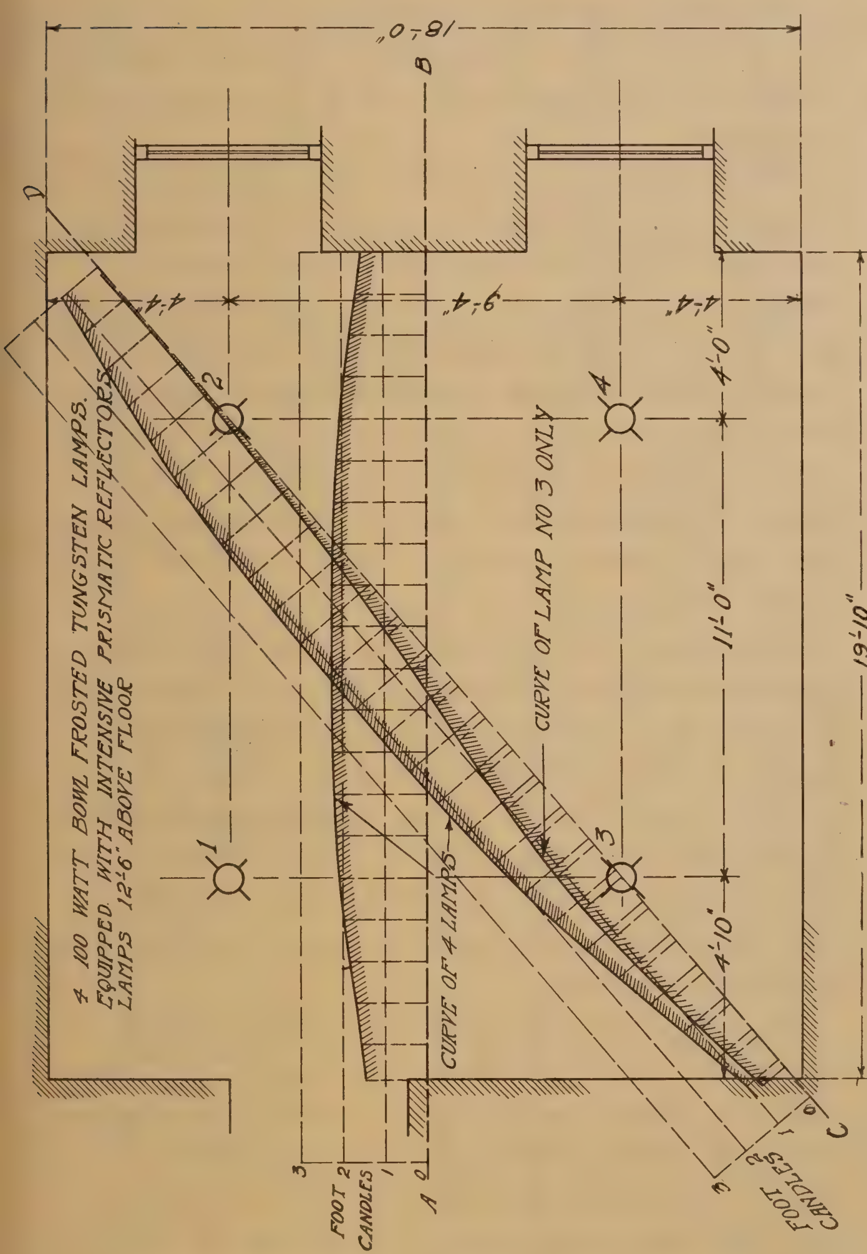


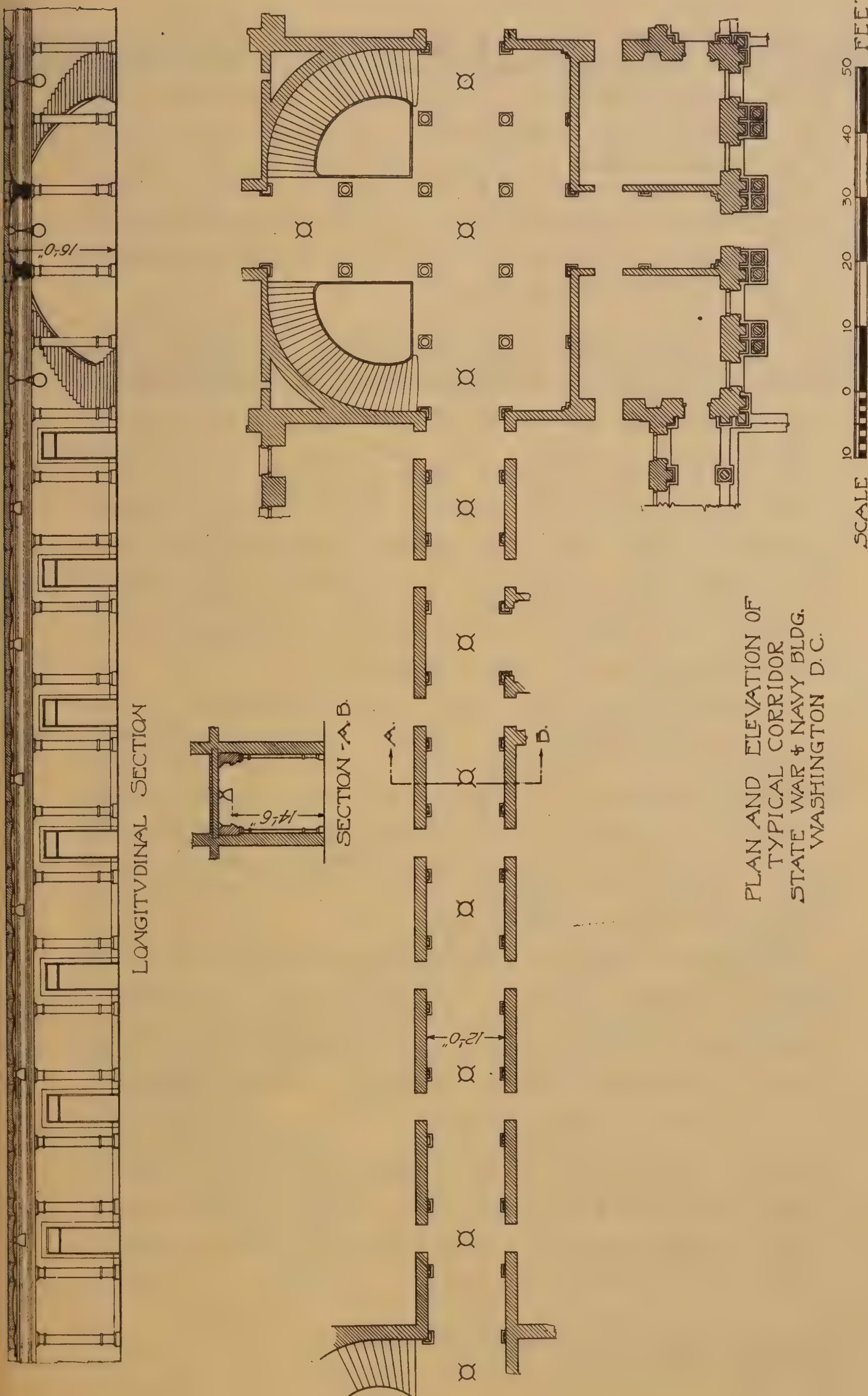
FIG. 18.—Distribution of Illumination on Reference Plane 2' 6" Above Floor, in Room Marked "A." State, War and Navy Building, Washington, D. C.

the diagonal. As the distribution of the light of each unit is symmetrical, the two curves showing the total illumination intensity derived from all of the lamps, afford a sufficient basis for predetermining the intensity at any point in the working portion of the room.

The illumination intensities shown in these curves are for the direct light of the lamps, and do not take cognizance of the added intensity due to reflection from the ceiling, walls and furnishings. To determine the actual intensity of illumination on objects in the room, the values given in the curves must be increased by an amount dependent upon the coefficient of reflection of the ceiling, walls, etc. To evaluate this coefficient, recourse must be had again to experience factors. If the room were furnished in light colors, and the walls unobstructed by high-standing furniture, the increase in intensity due to reflection might easily be equal to the intensity due to the direct light of the lamps; that is to say, the intensity of illumination on the working plane under these conditions would be double, or more than double, that shown in the curves in Fig. 18.

In a room of the size and type of that under consideration, with light-colored ceiling and moderately dark-colored walls, and with high-standing dark furniture along the walls, it is estimated that the increase in illumination intensity on the working plane, due to reflection from ceiling, walls, etc., will be about 40 per cent. Allowing for this increase, the actual intensity of illumination on the working plane in Room "A" will therefore be approximately 3 foot-candles (32.3 meter-candles). The distribution curves (Fig. 18) show that within the working spaces the minimum intensity of illumination will fall very little short of 3 foot-candles (32.3 meter-candles), and the maximum intensity will exceed this amount only very slightly.

Fig. 19 shows a plan and elevation of a typical corridor in the State, War and Navy Building. The width of the corridor is 12 feet (3.6 m.) and the height of the ceiling 16 feet (4.8 m.). The finish is in moderately dark colors. At various points along the corridor are located messengers' desks, at which a sufficient intensity of illumination for reading fine print is at times required. For the illumination of these corridors a system of general combined with local lighting is planned. A relatively high intensity of illumination is needed at the desks, whereas a low intensity of



LONGITUDINAL SECTION
16'-0"
SECTION-A.B.
14'-6"
A.
B.
12'-0"
PLAN AND ELEVATION OF
TYPICAL CORRIDOR
STATE WAR & NAVY BLDG.
WASHINGTON D.C.
SCALE
10 0 10 20 30 40 50 FEET

FIG. 19.

illumination will suffice for the other spaces. The lamps are mounted on the ceiling, and their location in the bays is dictated by the structural conditions. As a long row of lamps will be within the field of view of a person walking along the corridor, the lamps, even though mounted at a height of 14 feet 6 inches from the floor, are screened from view by a diffusing shade; 100-watt bowl-frosted tungsten lamps with intensive prismatic reflectors are used. The lighting units are placed from 21 to 25 feet apart, depending upon the structural conditions.

The distribution of illumination along the corridor is shown in the chart (Fig. 20). The representation presented in this figure reveals to the eye at a glance the foot-candle intensity of illumination on a reference plane 2 feet 6 inches (91 cm.) above the floor. The estimated foot-candle values shown are for direct lighting only, and must be increased by about 40 per cent to allow for the added intensity due to the reflection from the ceiling and walls in this case. This will give us an actual foot-candle intensity approximating 0.7 foot-candle (7.5 meter-candles) on the reference plane. On the desks in the corridor, local lamps will be used to bring the illumination at these points up to an intensity of at least 3 foot-candles (32.3 meter-candles).

In general, the intensity needed for corridor lighting is much lower than that needed for the lighting of office spaces. However, in this case the corridors require sufficient intensity for occasional reading and writing at the messengers' desks. If this intensity is supplied by a general system of lighting alone, it would be necessary in the case under consideration to expend at least two to three times as much power as would be required if the ceiling lights are supplemented by the local lamps.

The watts expended in the corridor for general lighting approximate 0.4 watt per square foot (4.3 watts per sq. m.), as compared with 1.1 watts per square foot (11.8 watts per sq. m.) in the office spaces. The foot-candle intensities on the plane of reference in the two cases bear substantially the same relation to each other as do the watts per square foot.

At the stairways in the corridor, the lamps instead of being backed by reflectors open at the bottom, are enclosed in diffusing globes, and mounted at a height of 11 feet (3.3 m.) from the floor. This change in glassware is made partly for aesthetic reasons, to break up the monotony of a long row of reflectors at the ceiling,

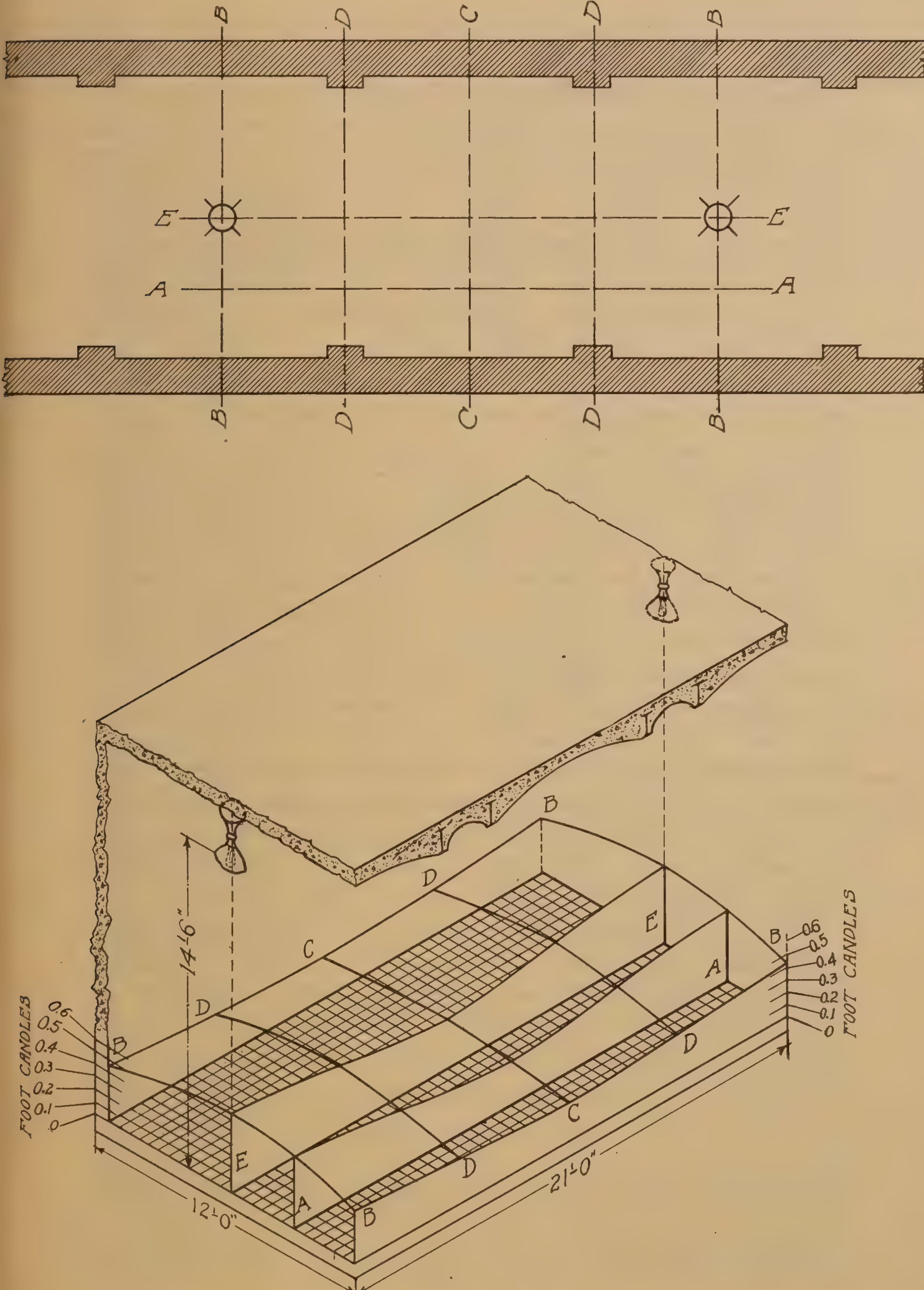


FIG. 20.

State, War and Navy Building, Washington, D. C.
Section of Corridor Showing Distribution of Illumination on Reference Plane 2′-6″ above Floor. With 100-watt Tungsten Lamps and Intensive Prismatic Reflectors.

and partly to permit of better lighting the upper portions of the stairs.

Lighting of a Public Library. The design of the lighting of a public library involves considerations that are somewhat different from those that obtain in the case just analyzed, but the general principles underlying the design are, broadly speaking, the same in both cases. A typical instance of library lighting is selected for discussion, namely, the design of the illumination of the new Carnegie Libraries in New York City. The following is a digest of a paper on this subject read at the convention of the Illuminating Engineering Society, October, 1908: *

The lighting design should aim to secure (1) sufficient illumination on the reading tables and book shelves to meet the demands of a wide class of readers of various ages and conditions of eyesight, taking into account the fine print in some of the books and the difficulty of reading titles of books in position on the shelves. Some of the books are worn out by frequent handling and the titles are more or less obscured; (2) the lowest practicable specific brightness of lighting sources; (3) freedom from glare of the lamps and glare of the illuminated objects; (4) sufficient illumination to provide a moderate reading light in all parts of the room; (5) moderate cost of installation; (6) economy of operation; this must take into account not only the system of illumination and type of lamps used, but also the switching arrangements; (7) simplicity of construction and convenience of operation; this must take into account the character of help in local charge of the equipment; (8) aesthetic design of the lighting fixtures and attractive appearance of the reading rooms at night.

The high foot-candle intensity required in the local working spaces dictated that the most economical system of illumination to suit the needs of the case was that of general lighting combined with localized lighting at the reading tables, shelves, etc.

Fig. 21 shows a plan of the first floor of such a library. With the exception of the vestibule and small offices which are separated from the rest of the room by glazed partitions, this floor constitutes one large room. In the front of the room is the circulating department; in the middle, the application and delivery desk;

* Design of the illumination of the New York City Carnegie Libraries. L. B. Marks, Trans. I. E. S., Vol. III, 1908, p. 538.

and in the rear portion, the free-standing bookcases and the reference room. These departments are separated from each other by low rails or low book shelves. Along the walls of the room are bookcases about 7 feet (2.1 m.) high. The public has access to all the book shelves. The walls of the room are cream-colored and the ceiling white.

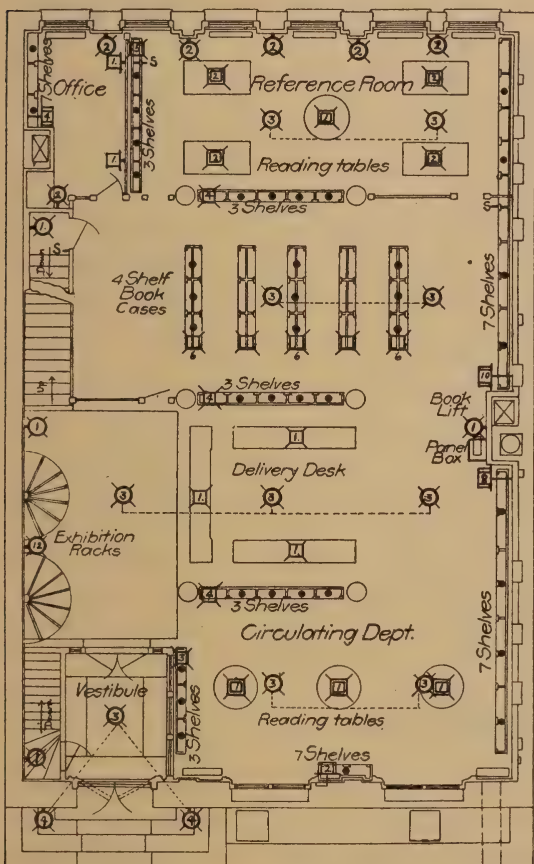


FIG. 21.—Plan of First Floor. Carnegie Library, New York City.

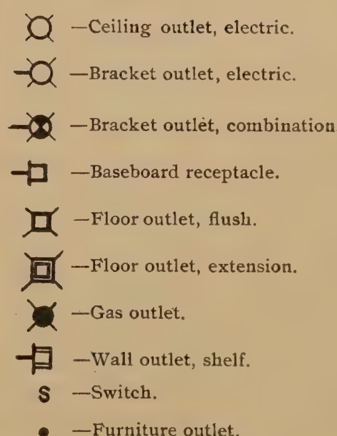


FIG. 22.

The location of the lighting outlets, switches, etc., and the position of furniture in the room are shown on the plan. The lighting units are designated at each outlet on the basis of 50-watt units, the unit in this case being a graphitized carbon-filament lamp.

Fig. 22 gives a key to the wiring symbols used in the plan.

For details regarding the exact type of lighting fixture used at each outlet, reference must be made to the original paper in which will be found a fixture and lamp schedule, giving specific information under the following headings:

(1) Fixture drawing.

(2) Number of lamps (gas and electric).

(3) Description of lamps (type and candle-power, clear or frosted).

(4) Glassware: globe, shade and reflector.

(5) Height of lamps above the floor.

The dimensions of the space to be lighted on the first floor may be taken as approximately 67 feet by 44 feet (20 m. by 13 m.), and the height of the ceiling 15 feet 3 inches (4.6 m.) in the clear. General illumination for this floor is furnished by ten 187-watt ceiling-pendant graphitized carbon-filament lamps, each lamp being enclosed in a diffusing glass globe 14 inches (35.5 cm.) in diameter. Tungsten 100-watt lamps have recently been substituted for the carbon-filament lamps in some cases. The height of the lamps above the floor is 12 feet 6 inches (3.7 m.). Localized illumination, separately controlled, is provided on the reading tables, book stacks, book shelves, etc., and may be used in whole or in part, depending upon the requirements. The free-standing four-shelf bookcases shown on the plans are located near the rear of the room and are 4 feet 4 inches (1.3 m.) high and 9 feet 6 inches (2.8 m.) long, divided into four shelves, 9 inches (23 cm.) apart. These are locally illuminated by two-arm fixtures equipped with 50-watt lamps, backed by prismatic reflectors, which are covered by opal shades, green on the outside. The bottom of these shades is 6 feet 6 inches (1.9 m.) above the floor. The shelves shown on the plans along the wall are seven-shelf bookcases, and are illuminated by lamps backed by mirrored trough wall reflectors holding lamps in a horizontal position, and equipped with 50-watt lamps. The low bookcases along the aisles have three-shelf cases, and are provided with local illumination from 8 candle-power lamps on swing brackets, which, when in use, extend 9 inches (23 cm.) beyond the edge of the case, but when out of use are swung over the top of the rack in order to leave the maximum aisle space. These lamps are backed by opaque metal reflectors.

The round reading tables noted on the plan are provided with local illumination from 40-watt frosted lamps in single-lamp fix-

tures having 14-inch (35.5 cm.) opal dome shades, green on the outside. Immediately over the lamps and inside of the dome shades are placed prismatic reflectors. These fixtures are placed at the centers of the tables. The lamps are 20 inches (50.8 cm.) above the table top.

A drawing of the table lamp referred to is shown in Fig. 23. It will be seen that the lamp and reflector are well up in the green-plated glass dome. In this position they are not seen by the reader seated at the table. The reflector is of such design as to give a bat-wing distribution curve of illumination; that is to say,

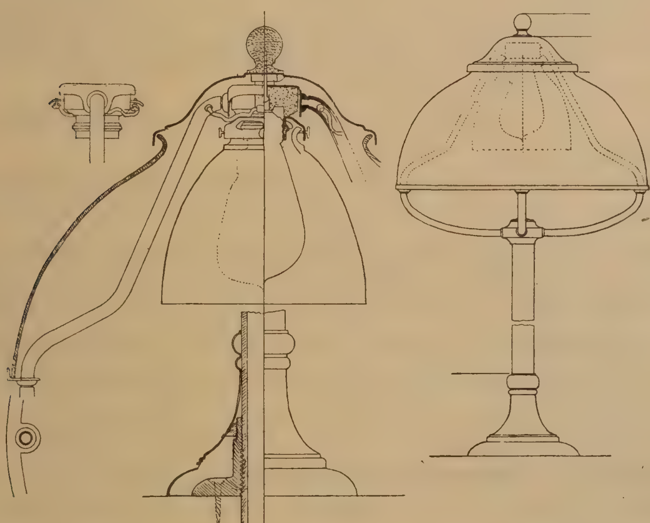


FIG. 23.—Table Lamp Equipped with Reflector Designed to Give a "Bat-wing" Distribution of Illumination.

the maximum intensity of light from the lamp is emitted at an angle of approximately 45° to 50° from the vertical, thus throwing the light out toward the edge of the table, where it is needed in reading.

Summary: The following may be named as the chief features of the design:

(1) No unshaded lamps used in the installation. Specific brightness of exposed lighting sources, 1/10 candle-power per square inch (0.016 c. p. per sq. cm.) of actual surface. Lighting planned to secure freedom from glare.

(2) General illumination combined with localized illumination.

(3) Intensity of general illumination substantially 1 foot-candle (10 meter-candle) on horizontal working plane.

(4) Intensity of illumination (horizontal) on reading tables, average working conditions 5 foot-candles (50 meter-candles).

(5) Intensity of illumination (vertical) on book shelves, 1½ to 4 foot-candles (15 to 40 meter-candles). Intensity of illumination (horizontal) on book shelves 4 to 8 foot-candles (40 to 80 meter-candles).

(6) Lamps for general illumination hung high, but low enough to avoid sharp contrasts of illumination on the ceiling.

(7) Lamps for table lighting provided with prismatic reflectors and designed to throw the maximum light sideways instead of downward. Frosted lamps used.

(8) Lamps for lighting low book shelves screened from view by opaque parabolic reflectors.

(9) Lamps for lighting wall bookcases backed by opaque trough reflectors.

(10) Wall-bracket and column-bracket lamps provided with enameled glass-diffusing shades of sufficient depth to completely hide the lamp from view. Bowl-frosted lamps used in these shades.

(11) Economy of operation and flexibility; switching arrangement for sectional control of local lighting; lights near windows placed on independent circuit; electrical connections from floor plugs to lamps designed to permit of shifting the tables.

Application of Asymmetric Distribution of Light. Fig. 24 shows a plan and section of an assembly room and lecture hall in a Carnegie Library building, New York City. The conventional style of lighting for a room of this character is to have a ceiling fixture in the center of each bay. The room in question, as will be noted from the plan (Section A-A) is only 11 feet (3.3 m.) high in the clear. The length of the room is 56 feet 6 inches (17 m.) and the width 38 feet 6 inches (11.5 m.).

The illumination of an audience room of this character presents difficulties that are not met with in rooms in which the ceiling is high. It is impracticable to dispose the lighting units on the side walls only, as such an arrangement would not, without undue sacrifice, give adequate illumination in the center of the room. If the lighting units are hung from the ceiling in the usual way, the center row of units will be within the visual angle of most

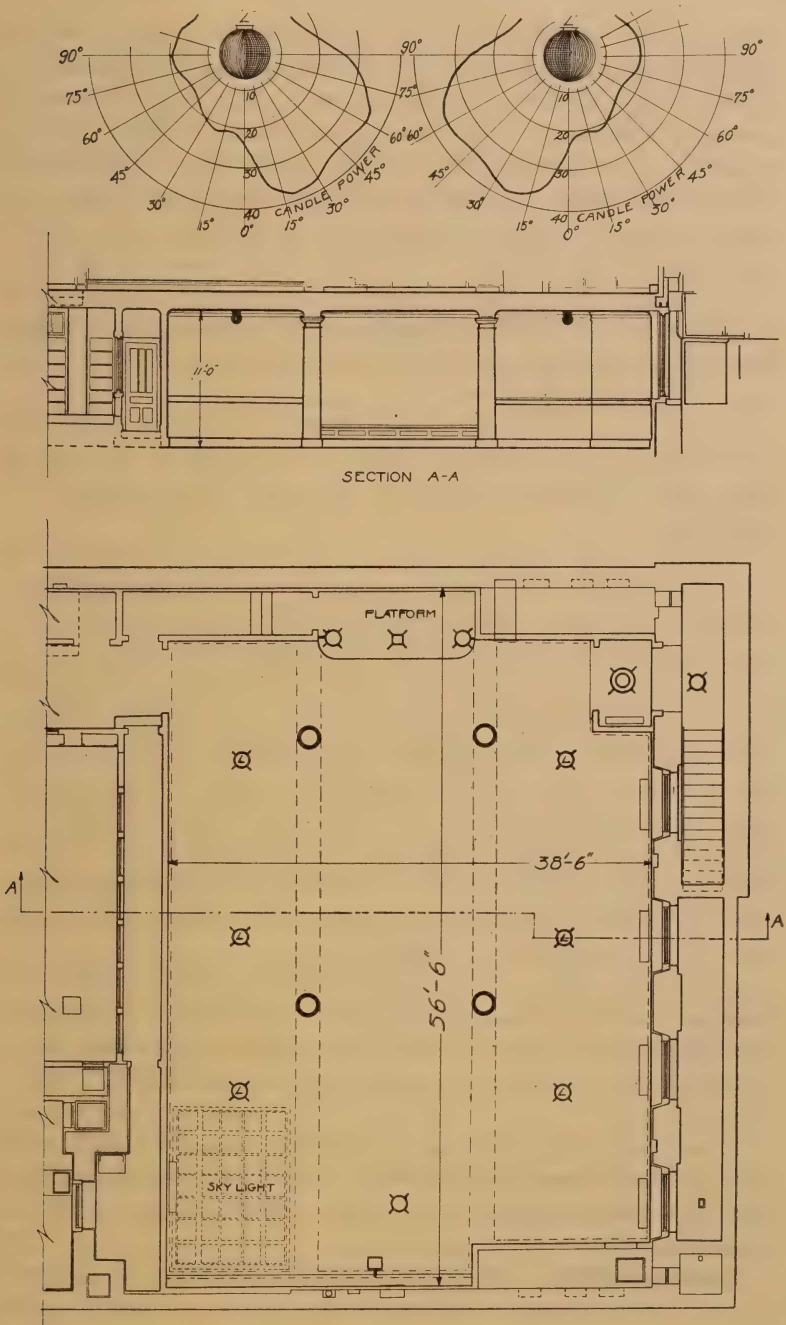


FIG. 24.—Assembly Room and Lecture Hall, Carnegie Library, New York City. Application of Asymmetric Distribution of Light.

of the audience. Moreover, the speaker in facing the audience will be compelled to face this row of lamps. Even though the intrinsic brightness of the lighting sources be kept within the lowest practicable limits, the strain on the eye of those attending a lecture in a room lighted in this way is very considerable. For aesthetic, and other reasons, a lighting system in which the lamps are mounted in deep opaque reflectors at the ceiling would not be practicable in this case.

One method of meeting the situation is presented herewith. This solution is offered only as a suggestion, but has the merit of having been successfully tried out in practice. Its application to other cases of lighting will be manifest.

In carrying out this method, each lamp is enclosed in a directing and diffusing prismatic-glass globe, mounted close to the ceiling. This globe is designed to give an asymmetric distribution of illumination.

With a 40-watt tungsten lamp, the distribution of candle-power in a vertical plane through the center of the diffusing prisms is shown in the curves at the upper part of the drawing (Fig. 24). The drawing also shows the general arrangement of the prisms. It will be noted that the directing prisms of globes on the left side of the room are mounted facing the left wall, and the directing prisms of globes on the right side of the room are mounted facing the right wall. The diffusing prisms of opposite lamps face each other. By this arrangement a large proportion of the total flux of light of the lamps is thrown sidewards, toward the center of the room, thus increasing the illumination at the center of the room to such an extent that an extra row of ceiling lamps in this section of the room is not needed.

There is an aisle space at each side of the room, the aisle seats being several feet from the side wall. The ceiling fixtures that are equipped with special globes to produce an asymmetric distribution of illumination are located at outlets marked "L" on the plan.

It may be remarked that while the intent of an illuminating design of this character is, primarily, to conduce to the visual comfort of the audience, the visual comfort of the speaker is insured at the same time.

Factory Lighting. We have discussed the design of illumination in a few typical cases that differ from each other in many

essential details. Another typical case will now be considered, which differs widely from either of the others, namely, the case of a factory lighting installation.

In the particular factory in question the proprietors had planned to install in a new mill a lighting equipment precisely similar to that which had been in use for many years in another mill operated by them. A demonstration was made to convince them that they could obtain vastly better results if the lighting of this particular class of work (manufacture of silk velvets, velours, dress goods, mohairs, worsteds, etc.) were accomplished by a system combining general and local illumination, instead of by strictly localized lighting as used in the old mill.

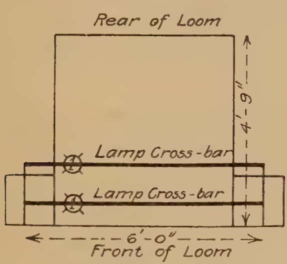


FIG. 25.—Factory Lighting. Plan of Lighting Looms by Strictly Localized Lighting.

In the weaving room of the old mill each loom was equipped with two 110-volt, 16-candle-power carbon-filament lamps backed by 5-inch by 10-inch tin reflectors, enameled white on the inside. This layout is typical of that which is used in many mills throughout the country. The plan (Fig. 25) shows the arrangement of lamps for lighting the looms in the old mill. One of these lamps lights the front and the other the rear of the loom. Each lamp is hung from a cross-bar specially provided on the loom to permit of lateral shifting of the lamp along the entire length of the loom. The distance from the lamp to the working surface of the machine is from 1 foot to 1 foot 6 inches (30 to 45 cm.). With this system of lighting, only that portion of the work immediately beneath the drop lamp is brightly lighted. If the lamp is at one end of the loom, the other end is in darkness. The operator shifts the lamp as he proceeds with the work to meet his requirements of illumination.

The lighting of this room is what is technically called "spotted" lighting. In looking along the room one sees a series of bright places or spots in a field of comparative darkness. Even though the surface illuminated by the spotted lighting be very bright, the eye is not capable of seeing as well for a prolonged period with lighting of this character as it is with lighting that is not so intense, but is more evenly distributed.

In the design of the lighting of the new mill, the object sought was to secure the proper intensity and distribution of illumination at the minimum expense. Economy of lighting was a very important consideration, but even though the power required for the new lighting system was considerably greater than that required for the old, the proprietors were convinced that the extra cost would be far more than compensated by the increase in output and the improvement in the quality of the work made possible by the new system.

In carrying out the lighting design consideration was given to (1) the character of the work done; (2) flux of light required; (3) color of the light; (4) economy of lighting and switch control; (5) type of lamp; (6) location of lamps and selection of reflectors with reference to (a) diffusion and direction of light and angle of vision; (b) intrinsic brightness; (c) accessibility; (d) exposure of eyes to heat of lamp; (e) dust shedding; (f) mechanical strength; (g) method of suspension of lighting units to minimize vibration.

For the lighting equipment of each pair of looms in the new mill, three 187-watt bowl-frosted graphitized carbon-filament lamps were originally used. Subsequently, the lamps were replaced by tungsten-filament lamps. Each lamp is mounted in an enameled prismatic-glass diffusing shade. Although the shade is open at the bottom, the sides project down so far below the base of the lamp that the latter is never within the visual angle of any of the operators. One lamp is centrally located above the front of each loom, and one lamp is located centrally above the space between the rear of two looms, as shown in the plan (Fig. 26). The front of the loom, and especially the central portion thereof, requires a higher intensity of illumination than the rear, and for this reason the arrangement of lamps shown in the plan was decided upon. The lamps are hung from the ceiling by duplex reinforced cords. The weight of the lamp and shade is taken by a porcelain

cleat, by which the drop cord is fastened to the ceiling. This insures a simple and durable construction and a sufficiently elastic suspension to absorb any vibration or jarring caused by the operation of the machines.

The height of the bottom of the shades is 6 feet 3 inches (1.9 m.) above floor level.

The distribution of illumination over the working surface of the loom is shown in the chart (Fig. 14), which was presented in Lecture I. It will be noted from this chart that the distribution of illumination on the working surface of the looms in the new

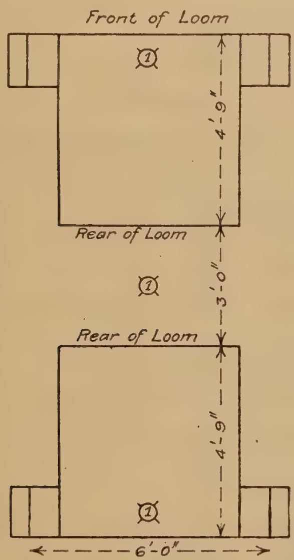


FIG. 26.—Factory Lighting. Plan of Lighting Looms by General Illumination Combined with Directed Lighting.

mill is fairly even, and that the distribution of illumination on the looms in the old mill is decidedly uneven. To secure good results in illumination it is absolutely necessary that the intensity of illumination on the work should not fall below a definite minimum, and that excessive contrasts in intensity should be avoided. In the old mill, to obtain sufficient light on the work, the operator must actually shift the lamp along the length of the machine as the work progresses. In the new mill, the lights are out of immediate reach and their location is permanently fixed. The measurements show that in the old mill the intensity of illumination

at one end of the working surface of the loom is nearly 100 times the intensity at the other end. This wide variation occurs within a working space of only 3 feet (0.9 m.). In the new mill, the maximum variation between the most brightly lighted part of the machine and the dimmest portion is about $2\frac{1}{2}$ to 1—a ratio which is well within the limits permissible.

An examination of the chart brings out strikingly the fact that in the old mill the intensity of illumination on the machine at night, directly underneath the drop lamp, is more than $2\frac{1}{2}$ times the intensity of daylight on the machine at 3 p. m. on a bright day, and more than 6 times the minimum intensity that is sufficient for the work in daylight.

In the new mill, the maximum intensity of artificial light is less than the intensity of daylight at 3 p. m., and the minimum intensity of artificial light on the working portion of the loom slightly exceeds the minimum intensity found sufficient for the work in daylight.

In the old mill, little if any advantage is taken of the reflecting value of the ceiling and walls, whereas in the new mill the reflection from ceiling and walls is used to great advantage in securing diffusion of the light.

In the old mill there is a strong glare from light reflected by the bright surfaces of the machines. This glare reduces the sensibility of vision and causes eye-strain. In the new mill, the direction and diffusion of the light is such as to reduce the glare to extremely small proportions.

Windows and Skylights for Direction and Diffusion of Daylight and of Artificial Light. In Lecture I attention was directed to the advantages to be gained by the use of prismatic glass in windows for the daylight illumination of factories and other interiors.

The use of prismed windows for the direction and diffusion of daylight suggests the possibility of applying artificial light outside of the windows in such a way as to secure the same lighting effects as are obtained in the daytime. Obviously, there are, in general, two limitations that stand in the way of the accomplishment of such a plan: first, on the score of economy of production of effective light flux; and, second, on account of structural difficulties and objections arising from the placement of the lamps. There are many cases, however, in which neither of these limitations necessarily applies.

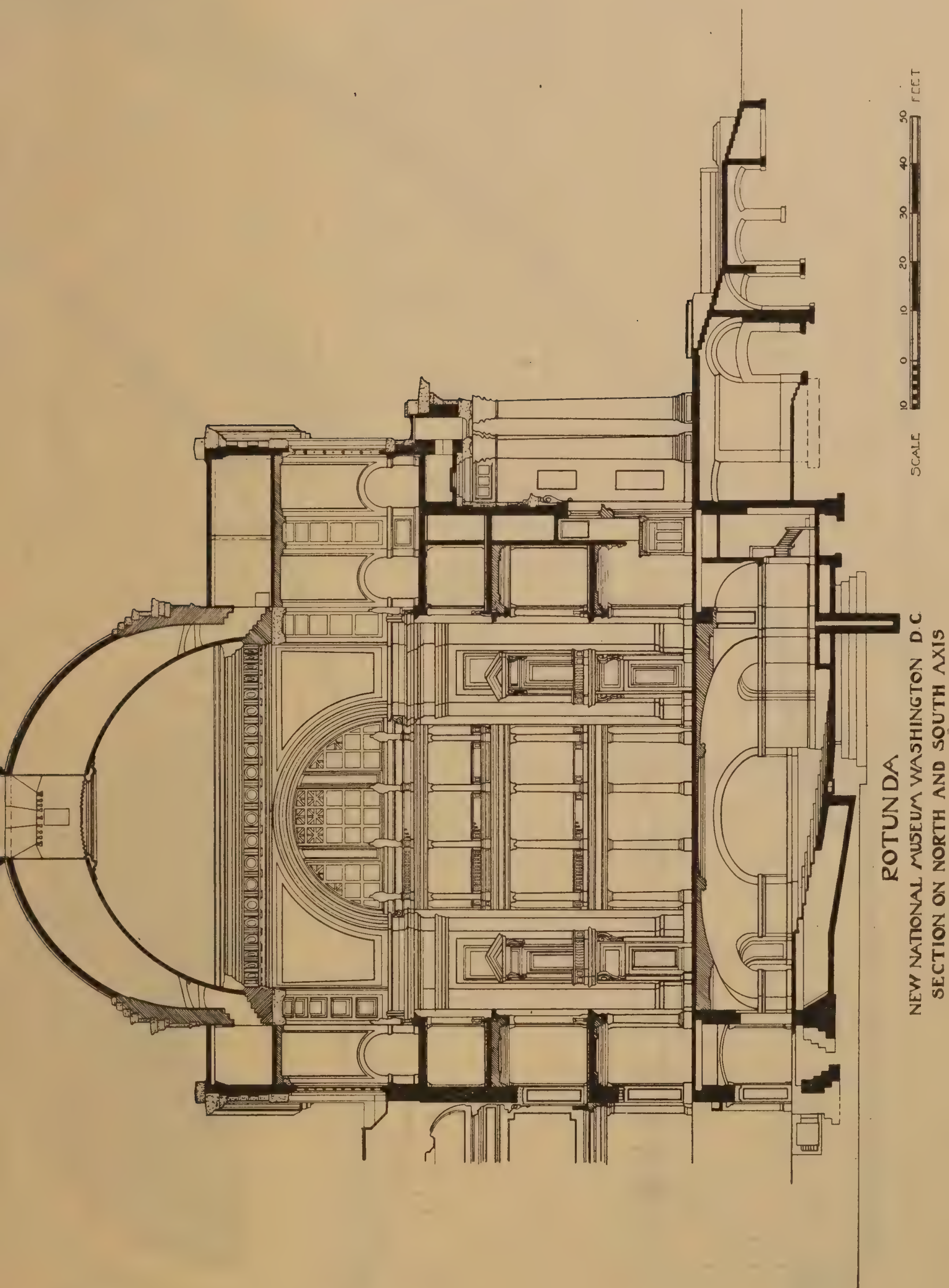
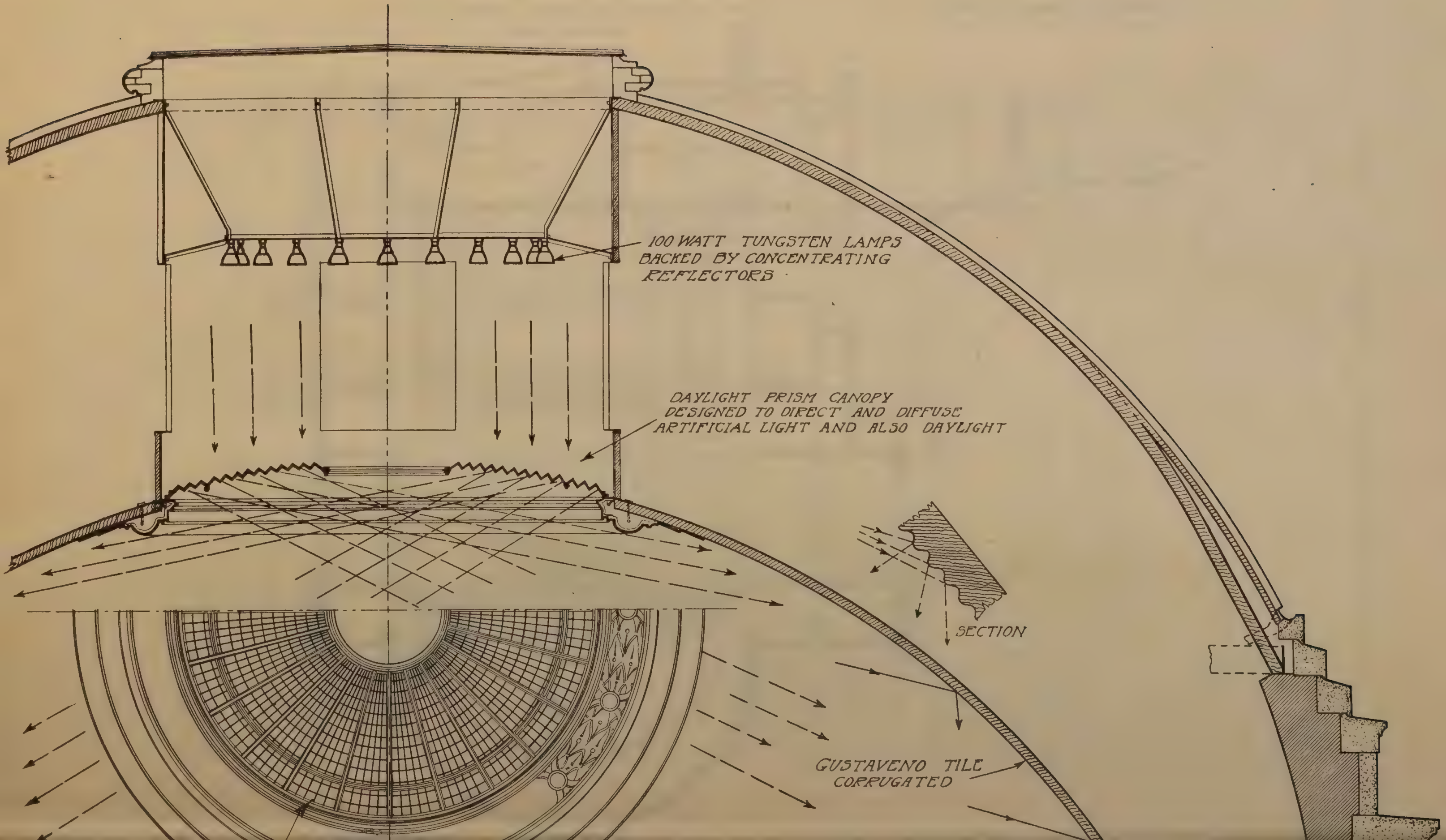
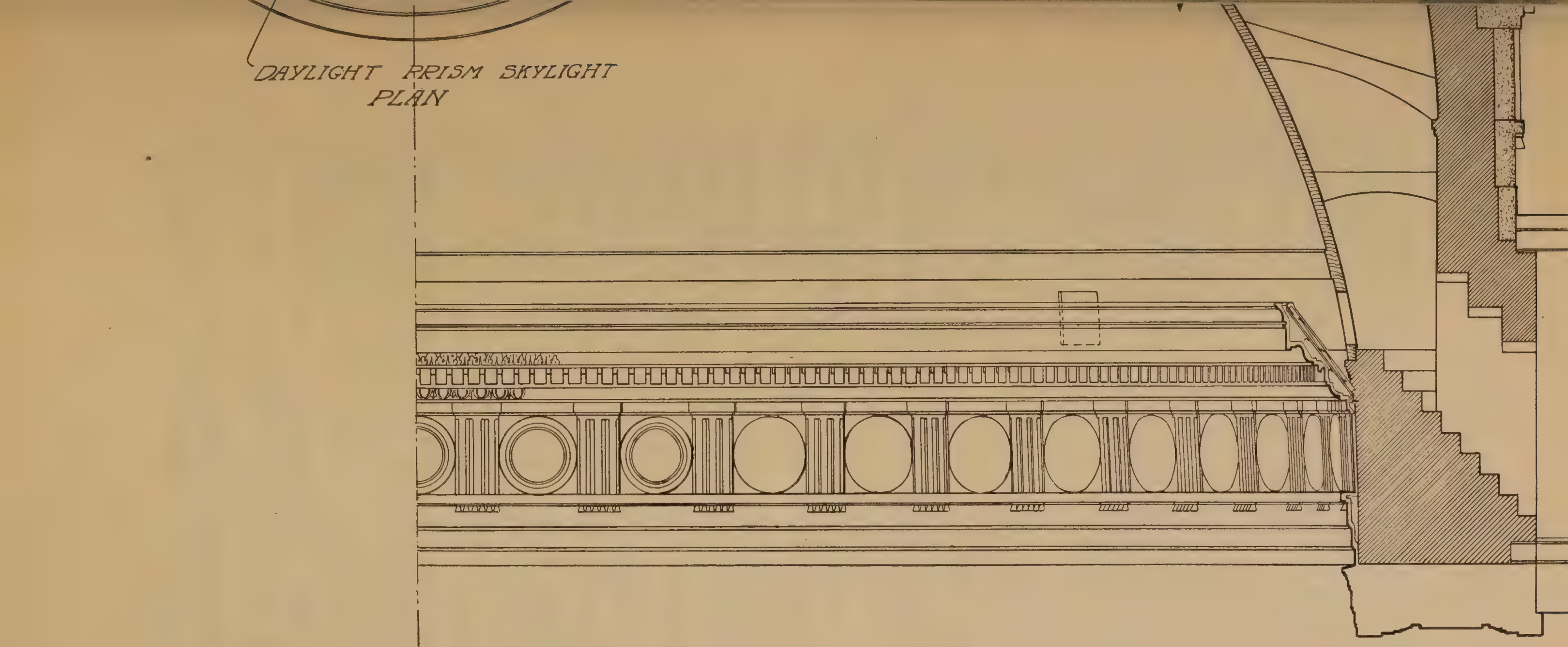

SCALE
10 0 10 20 30 40 50 FEET
ROTUNDA
NEW NATIONAL MUSEUM WASHINGTON D C
SECTION ON NORTH AND SOUTH AXIS

FIG. 27.



100 WATT TUNGSTEN LAMPS
BACKED BY CONCENTRATING
REFLECTORS
DAYLIGHT PRISM CANOPY
DESIGNED TO DIRECT AND DIFFUSE
ARTIFICIAL LIGHT AND ALSO DAYLIGHT
SECTION
GUSTAVENO TILE
CORRUGATED



NEW NATIONAL MUSEUM WASHINGTON, D.C.
SECTION OF ROTUNDA DOME
SHOWING DAYLIGHT PRISM SKYLIGHT
ADAPTED FOR NATURAL AND FOR ARTIFICIAL LIGHT

SCALE 5 10 15 FEET

FIG. 28.

Below is given an outline of the plan pursued in attempting to solve this problem in one case in which the lighting design contemplates the use of a prism skylight for the direction and diffusion not only of daylight but of artificial light. The application of the principles involved to other installations of a widely different nature will be manifest.

Fig. 27 presents a sectional view of the rotunda of the new National Museum, Washington, D. C., and Fig. 28 shows a section of the rotunda dome in which a daylight prism skylight is adapted for the direction and diffusion of natural and of artificial light.

Daylight prisms to be effective must, perforce, be designed for incident rays that are parallel to each other. Therefore, the first step in planning a lighting scheme in which the glassware is well adapted for the distribution of both natural and artificial light, is to secure substantially parallel incident rays from the artificial light. With most artificial sources this involves the redirection of the rays of light by means of parabolic or equivalent reflectors.

Referring to the drawings of the Museum building, daylight enters the eye of the dome and reaches the prism canopy, shown in the plan. The direction of the incident light is indicated by the parallel arrows above the canopy.

The prisms are designed to redirect the light in the direction indicated by the arrows to the corrugated tile surface of the dome, from which surface the light is reflected downward. In this way, the light from the sky, instead of passing directly downward through the small eye of the dome, is diverted from this course and spread over the entire surface of the dome, which latter becomes a secondary lighting source. It will be noted that the design is such that most of the emergent rays cross each other immediately below the prism canopy, and thereafter impinge on the inner surface of the dome. The corrugated surface of the tile, which is light in color, insures an effective diffusion of the light.

The artificial lighting sources (100-watt tungsten lamps) are located in a circle 10 feet (3 m.) above the daylight prism canopy. Each lamp is backed by a highly concentrating reflector, to secure substantially parallel rays. The direction of the incident and emergent rays in this case will be practically the same as in daylight.

The aim of the lighting scheme in this installation is to secure economically and in a simple way substantially the same light and

shade effects by night as obtain in daylight. Aside from the other advantages of this plan of lighting, the architectural features of the building will be seen to advantage by artificial light as well as by natural light. The actual foot-candle intensity on the "working" plane in this case is held to be of secondary importance.

The plan showing the section of the rotunda is presented to give a general idea of the arrangement of the building and the relation of the rotunda to the other parts of the building. However, the additional lighting equipment provided for the illumination of the rotunda is not shown on the drawing, as the present discussion is limited to that part of the lighting scheme adapted for the use of both natural and artificial light.

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XIII (3)

PRINCIPLES AND DESIGN OF INTERIOR ILLUMINATION

By Norman Macbeth

In discussing the principles and design of interior illumination with gas lamps, much headway may be made by the simple statement that the principles which have been so fully covered by Mr. Marks as applying to electric radiants will apply, with very slight modifications, indeed, to the problems presented in the gas field. It is also hardly necessary to say that all calculations from photometric curves from gas lamps are subject to the methods of calculation described by Mr. Barrows.

It is unlikely in this series of lectures that we will get away from our previous fundamental specifications as to "what is an illuminating engineer," and so the exception may be noted that the illuminating engineer who turns to gas radiants for his aid must depend, not like the electrical engineer, upon common sense, but upon uncommon common sense.

In the gas illuminants we have many advantages. The general backwardness in making the most of these advantages is, I have been convinced, largely due to the high efficiency from coal pile to effective illumination, and a consequent careless regard for results. If the gas company's existence depended more largely upon the lighting side of the business, more attention would be given this subject, and correspondingly better results would be secured.

Color Effect

For years we have been told that the color effect of the light from a mantle burner was the most disagreeable of the artificial sources, also that an artificial source to be satisfactory should give a light of about the same color value as daylight. Credit is due to many scientists and members of the Illuminating Engineering Society * for investigations which have shown that with incan-

* Transactions Illuminating Engineering Society, Vol. 3, 1908, p. 625. The Illuminating Engineer, Vol. 4, 1909, p. 434.

descent gas mantles we can approach nearer to a white-light value than with any of the electric incandescent lamps. A reasonable objection to the ordinary mantle lamps is that they give a light which is too near a white light. The predominance of open flames in residence work to-day must be largely due to this question of color. For rest, relaxation and comfort, we undoubtedly prefer a lamp which does not give a white-light effect, but one which will be richer in the orange and red rays. While it may not be generally known, this is at the option of the purchaser. If the near white light is not desirable, we have a range of color from a purplish-white through to the orange-yellow, a color which, when compared with a 4-watt carbon filament, makes the light from the carbon appear like white light. Mantle manufacturers can meet the demand for any desired color within the above-mentioned range.

Specific Intensity

In "specific intensity," a very important consideration, indeed, with all our modern high-powered radiants, the mantle is again particularly fortunate, ranging from 65 candle-power per square inch, or 10 candle-power per square centimeter, with those mantles made from cotton; 70 candle-power per square inch, or 10.8 candle-power per square centimeter, with artificial silk, to 85 candle-power per square inch, or 15.1 candle-power per square centimeter, with ramie fiber. These figures are based on calculations of the actual area of the fiber in the mantle, deducting for the small spaces between the threads. However, as the relation of the so-called actual area to the apparent area was taken at 65, 75 and 60 per cent, respectively, the above intensities may be reduced in proportion by those who prefer to take the entire area (the product of the width and height in the horizontal projection) as the actual area.

Owing to the closeness of the mantle weave, we are not subject to striation effects with reflectors having smooth, polished interiors, and hence many of the ordinary reflecting surfaces which should not be used with electric incandescent lamps are available for gas lamps.

Radiant Heat

On the subject of the radiant heat from gas lamps, many investigations have been made; the most recent were reported in a

paper before the recent convention of the Illuminating Engineering Society.*

Dr. F. Ballner reported † on a series of tests, and also referred to tests made by Rubner, who discovered that, from the standpoint of radiant heat, "the petroleum lamp was the least advantageous source . . . ; the Welsbach light being the best, and the electric glow lamp the second."

"According to Rubner, the total evolution of heat from a glow lamp is only one-sixth of that of the incandescent gas burner," while "the radiant heat of the Welsbach burners represented 17 per cent of the total heat; whereas, the radiant heat of a glow lamp is 71 per cent of its total heat."

Psychological Considerations

If gas men were students of psychology, and advertised more generally, we could expect something like the following, which is an abstract from an electric fan ad:

"If they do not have the effect of actually reducing the temperature, they will at least create the illusion of coolness, which reacts in the most favorable manner upon your customers, your employees and yourself." Or from a portable lamp ad: "Cool, green shades, a warm-weather specialty"; and that with an electric lamp which may be placed in a position to deliver more radiant heat on the person of the purchaser than a gas lamp which would be equally effective from an illumination standpoint with a possibility of less radiant heat.

There has been a great deal of misunderstanding generally on this question of heat. Aside from all questions as to how much of the heat is radiant and how much is carried off in the air currents, that is, convected, it is a very simple matter to determine the total amount of heat liberated by either gas or electric lamps. With either of these lamps, the luminous efficiency is so low that practically all the energy may be considered as effective heat. The total heat from the gas lamps will, of course, be the product of the consumption in cubic feet per hour, and the heating value of your

* The Temperature Rise due to the Energy Radiated in the Lower Hemisphere from Different Light Sources, J. G. Felton and E. J. Brady, Transactions Illuminating Engineering Society, November, 1910.

† Journal of Gas Lighting (London), May 8, 1906; and, The Illuminating Engineer, Vol. 1, pp. 325-328.

gas in British thermal units per cubic foot; while with the electric lamps the calculation may be determined by the wattage of the lamps at the heat equivalent of 3413 B. t. u. per kilowatt-hour. Considered on the basis of equal light output or an equal illumination effect, the more efficient types of gas lamps rarely liberate more than two or two and a half times the heat equivalent of the better grade carbon-filament incandescent lamps.

With gas at 600 B. t. u. per cubic foot; hard coal, 14,000 B. t. u. per pound or 875 B. t. u. per ounce, a lamp consuming 3.3 cubic feet per hour will liberate 2000 B. t. u. per hour, which is equal to a piece of coal having a weight of 2.3 ounces. A lamp consuming 4½ cubic feet per hour will liberate 2700 B. t. u. per hour, or equivalent to a piece of coal weighing 3 ounces. An open gas flame using 8 cubic feet per hour, or 4800 B. t. u. per hour, will have a heating effect equivalent to 5½ ounces of hard coal.

Therefore, in the production of light from an ordinary gas lamp consuming from 3 to 4 cubic feet of gas per hour, we are liberating that quantity of heat equivalent to the combustion of 2 to 3 ounces of hard coal, which would be approximately equal to a cube of coal 1½ inches square, if this combustion was prolonged over 1 hour. If the combustion should take place in 5 minutes, it would liberate that quantity of heat equal to the product of 12 gas lamps in the same time. Heating experts would not be likely to attempt to heat a room with a small cube of coal suspended 6 or 7 feet above the floor, nor would they consider such a system very efficient, allowing 1 cube of coal per 100 square feet; and yet it has been stated that we can heat a room most wonderfully with a gas lamp.

As has been previously stated by the writer, undoubtedly much of the heat argument which has been advanced against gas illumination comes from the general association of "where we have light we have heat." "Dark and cool" is more often associated with cellars and cold-storage warehouses than with stores using gas for illumination. Illumination is more often delivered at higher intensities with gas than it is with electric lamps, and as the human eye is not capable of properly appreciating these high intensities, nor do consumers generally have illuminometers, we undoubtedly suffer by not getting credit for the amount which has been delivered.

Hygienic Considerations

On the one other bugbear—vitiation of air—all who are seeking dependable information on this matter should study a report * of 83 pages on "The Relative Hygienic Values of Gas and Electric Lighting," given by Samuel Rideal, D. Sc., F. I. C., who is a Fellow of the Royal Sanitary Institute, and an authority well above prejudice.

This is perhaps the most exhaustive, complete and scientific series of tests ever reported. In two adjoining rooms of about the same size and structural arrangements, illuminated alternately by gas and electricity with lamps having approximately the same light output and resulting in equal effective illumination, 15 men were subjected on more than 50 occasions, during a period of over 3 months, to some 6000 tests of the kind best calculated to detect any falling off in condition as might be expected to take place under either mode of illumination. To quote from the report: "The results of these tests have been carefully examined and averaged, and, with few exceptions, they absolutely fail to disclose any measurable difference between one mode of lighting and the other. Not only so, but in no case do they show any deviation from any normal conditions.

"Although gas combustion originally develops more heat than electricity does, it was found that the final result was equalized by the following causes:

(a) The gas burners gave rise to stronger air currents, and invariably produced a more active ventilation and diffusion of air than electric lights; hence, along with the products of the gas burning, the exhalations from the persons present were more rapidly removed.

(b) The ascending currents of air from the gas lights on reaching the ceiling rapidly parted with their heat, which was conducted away by the rafters and joists.

(c) The electric lamps really produced more heat than is commonly credited to them.

"This seems to be the explanation of the unexpected result that the average temperature of the rooms was practically the same under either illuminant, and that the electric light did not show the superiority in coolness usually claimed.

* Journal of the Royal Sanitary Institute, Vol. XXIX, 1908, No. 2.

"The relative humidity of the air was in general 70 to 75 per cent during the experiments, and was, therefore, such as the best authorities have laid down as most agreeable. On the score of the humidity the use of either illuminant is therefore consistent with correct hygienic conditions.

Effect on the Eye

"In the ophthalmic experiments:

(a) The sensitiveness of the eye to light as measured in the perception test is diminished very markedly after the exposure to the electric light, while no corresponding effect is noticeable after the eye has been subjected to the gas light.

(b) The power of co-ordinating and using the motor muscles of the eyeball recorded in the orbicular muscle tests was diminished to a greater extent after subjection to electric than to gas light.

(c) It was found that the ciliary muscles of the eye are more accommodative after 3 hours' exposure to the 50-candle-power light from the Darwin incandescent mantle than after a similar exposure to a 50-candle-power electric light.

(d) The acuity of vision by the retinal test again shows that the optic nerve or center was more susceptible in the case of gas illumination.

"There may be, and doubtless are, persons so peculiarly constituted as to find one light or other objectionable, or even to be unable to tolerate any artificial light whatever. Such cases belong to the domain of pathology rather than that of hygiene. On a review of the whole of the facts collected, it may be said, without reservation, that there is nothing in either mode of lighting which is incompatible with the best hygienic conditions.

Conclusions by Rideal

"The main conclusions may be therefore summed up as follows: Owing to the better ventilation obtained by gas, the products of combustion are not found in the air in anything like the proportion which might be expected, the temperature and humidity in any occupied room being no greater than when the room is lit with electric light.

"Carbonic acid has not the injurious effect which was formerly attributed to it, but considerable rises in the temperature and moisture content of a room, from whatever source, do have a preju-

dicial effect upon the well-being of the occupants. Even under adverse conditions of ventilation purposely created for this inquiry, neither the temperature nor percentages of moisture in the room reached a point at which any such effect could be detected by any of the recognized physiological tests.

"It has been established that the products, viz., heat, carbonic acid and moisture, so far as they modify the health of the occupants of a room, are derived from the inmates more than from the illuminant, and that a room of moderate size can be efficiently lighted by gas without sensibly affecting the amount of these three factors.

"The medical conclusions are in accord with those arrived at from the chemical and physical data, and also demonstrate that the choice between the two systems of lighting does not depend upon hygienic considerations."

A Ventilation Problem

A further noteworthy reference may be made to the recent action of the Committee of the Society of Medical Officers of Health, of London,* who, desiring to have their offices, and especially their meeting room, well lighted and ventilated, installed gas for illumination. A room, 24 feet square with a 13-foot ceiling, in which 150 members assemble at night, presents a problem in ventilation requiring careful attention. The members of this committee could be depended upon to go farther "than the elementary stage, that in the combustion of all gases there must be products of combustion, while with electric incandescent lamps there are not." It was found "that with gas, the products were harmless, and that the use of gas assisted in producing the circulation of air in the room; while, on the other hand, where electric lights were employed, and a number of people were gathered together, the lamps did not assist in the circulation of the air, that there was stagnation, and, consequently, in a short time, the exhalation of respiration charging the air caused it to be unwholesome to those who had occasion to remain in such an atmosphere."

"It is an error to assume that carbon dioxide is responsible, even in extreme cases, for the ill effects of bad ventilation. Also, that the discomfort due to bad ventilation is due to the reduction of the amount of oxygen in the air.

* Journal of Gas Lighting, October 18, 1910.

"The real source of trouble is moisture, and especially that odorous moisture emanating from the body, either by evaporation or exhaled from the lungs. The removal of this moisture is a matter of necessity, and the obvious method is by ventilation." *

Lighting and Ventilating Fixture

In Fig. 1 is shown a distributed unit ceiling fixture developed by a combination gas and electric company for the illumination of the gas side of their showroom and offices, and the successful

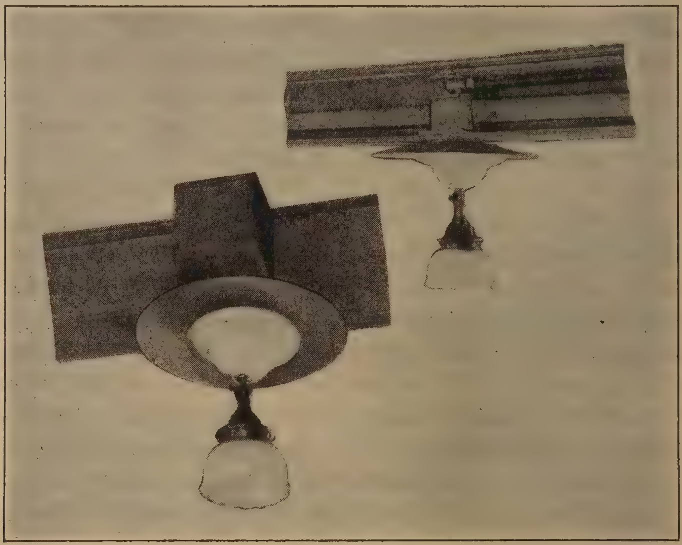

FIG. 1.—Ventilating Ceiling Unit.

ventilation of the entire room, utilizing the heat energy from the gas lamps to induce a proper circulation of air and carry off the vitiated air due to the occupants of the room; the other kind of vitiated air—that from the products of combustion—has never been known to harm either animals or human beings. The detail of construction of this unit is rather evident from the illustration. In the upper right-hand section is shown the galvanized-iron duct lining, which is continuous throughout the false-ceiling beams, connecting with flues in the walls leading to the roof.

* From a paper on Modern Gas Lighting, given before the architects and builders of the City of Detroit, June 9, 1908, by M. C. Whitaker.

That much more attention is being paid to this kind of work is evident from the somewhat similar experiences in many cities.

A recent experiment with a gas lamp consuming 18 cubic feet of gas per hour, installed 6 inches below the opening of a stack having an area of 1.7 square feet, and but 8 feet long, leading upwards into another floor, showed that over 35,000 cubic feet of air per hour were taken through this stack, nearly 2000 cubic feet of air per cubic foot of gas per hour.

An Installation for Ventilation

Reference might also be made to a gas office in a one-story building 20 feet by 70 feet, an area of 1400 square feet, having a ceiling 11 feet high, where 56 gas lamps were burned from 4.30 p. m. to 7.30 a. m. for display purposes. On opening the office at 8 a. m. the CO_2 content was found to be as high as 26 parts in 10,000, but after a thorough ventilation by way of the doors and windows this was reduced to 4 parts by 9 a. m. As the lamps were all put on again at 4.30 p. m., it was found that the CO_2 content at 5 p. m. reached 9 parts in 10,000.

Now, the condition which had to be met was how to increase the lamps used from 56 to 71, as was desired in making a more attractive showroom, and also take care of the rather serious ventilation conditions present and anticipated. A change was made in the hot-air furnace in the basement and, instead of drawing the cold air from the basement floor, the cold-air duct was continued to the outside; then the fresh air, which was also screened in this cold-air duct, passed around the furnace and through the three regular registers in the floor of the showroom. Four ordinary ventilators were then installed on the roof, connecting with 7-foot stacks to the ceiling of the showroom. With an increase of nearly 30 per cent in the number of lamps used, the ventilation results were as follows: At 8 a. m., with 71 lamps on from 4.30 p. m. the day before, the CO_2 content was less than 8 parts in 10,000; this was reduced to 3 parts, the amount which is always present in fresh air, by 9 a. m.; and at 5 p. m., the close of the business day, it had raised to only 5 parts in 10,000, and this with the doors and windows closed. The cubical contents of this room were 16,500 cubic feet, and on windy days the ventilators passed over 20,000 cubic feet of air per hour; and on days when the wind was slight or absent, over 60,000 cubic feet of air per hour, resulting by this method

alone in a change of air in this room from $1\frac{1}{4}$ to $3\frac{1}{2}$ times per hour. With a higher building and longer vertical stacks, the quantities of air passed would be largely increased.

Ordinary Ventilation

A. P. Beardsley * says: "It is surprising how often the air changes even in a room where no special attention is paid to securing good ventilation. Fresh air passes in through crevices of doors and windows in the lower half of a room, and out through similar openings in the upper half, as well as through fireplaces and chimney openings. Even the walls themselves help in the ventilation. Experiment has shown that 7 cubic feet of air per hour pass in from outside through a square yard of wall where there is a difference of 40° of temperature inside and outside."

You are all familiar with the experiment of blowing through a brick and extinguishing a lighted candle on the other side.

The conclusion may be drawn that any room which is so securely closed up that the number of mantle burners necessary for its proper illumination, or even several times that number of burners, will show an appreciable effect on its atmosphere, is unfitted for human habitation, even if lighted by daylight. The necessary arrangement for ventilation on account of hygienic considerations will also take care of all products of combustion, and the heat from incandescent gas burners may be depended upon to insure the proper ventilation which might otherwise require an elaborate and costly ventilation installation.

Reports covering many phases of investigations along lines similar to those noted above will be found in the following-named publications:

Report of the U. S. Dept. of Agriculture, Bulletins Nos. 109 and 175.

Year-Book of U. S. Dept. of Agriculture, 1904.

Smithsonian Contribution to Knowledge, Vol. 29.

Government Blue Book, 1902.

"Journal of Gas Lighting" (London), November 25, 1902; Vol. XCIV, page 374; XCV, page 449; XCVIII, page 918; C, page 423; CVI, page 821; CIX, pages 39 and 865; CX, page 18; CXII, page 648.

* Light, Vol. 6, March, 1906.

"Gas World" (London), Vol. XLVI, page 832; XLVIII, pages 149 and 327; L, page 299.

"Light," Vol. VI, page 8; VIII, page 59; X, page 119.

"Progressive Age," Vol. XXVII, page 561.

"Illuminating Engineer," Vol. IV, page 479.

Effect of Various Pressures

One of the most important considerations is the effect of pressure upon the lamps and burners used. Before the days of fuel appliances and incandescent mantle burners, the pressure of supply was influenced by the open-flame requirements. As open flames were generally most efficient at pressures of 1 inch, or ten-tenths of an inch, of water or less, and as many open flames are still in use to-day, the pressure conditions throughout the country vary greatly; this is also true in many cities where the pressure is largely affected by local conditions.

In a small town with absolutely level districts, with a centrally located gas works, a fairly even pressure can be maintained. This condition is, however, exceptional, and, as a rule, owing to the variation in levels of different districts, owing to various diameters of gas-supply mains and the extreme distances to which gas has to be conducted from the works, a higher initial pressure is required to insure a sufficient supply to the most distant consumers, and to those located in the low-lying districts. In some cities high-pressure distributing mains are used with district governor stations, while in other cities, again, the condition of the distribution systems is such that high pressure is prohibitive.

Managers of gas companies have many ideas as to the most satisfactory pressure for their mains and for their consumers, and as a consequence the pressure may vary from less than ten-tenths or 1 inch of water up to 10 or 12 inches, the latter being rather the exception, as very few plants, indeed, run their pressure beyond 8 inches.

Horizontal Candle-Power Measurements

As the distribution of light from an open-flame burner is of almost equal intensity in all directions, that is spherical, the intensity taken in the horizontal plane normal to the flat side of the flame may be properly considered as a measure of the mean intensity, and be used as a basis for calculating the efficiency of the

burner and the candle-power of the gas. Many photometricians improperly rate incandescent gas lamps by this same method. This is perhaps not so serious with the upright lamps, having a symmetrical distribution with practically equal portions of light flux in the upper and lower hemispheres and delivering the maximum on the horizontal, as it is with inverted lamps, the distribution from which may be in the proportion of from 75 to 90 per cent in the lower hemisphere and 25 to 10 per cent in the upper hemisphere. The horizontal reading of the intensity on a lamp of this kind certainly does not represent the same proportion of light flux as a horizontal reading on an upright lamp.

Added to this is the condition that the characteristics of various burners at different pressures vary widely. A burner may have a particularly high efficiency or duty at one special pressure, and at all pressures above and below that particular point may fall off very rapidly. This is illustrated in Fig. 2, which shows considerably different results with several burners under various pressures up to 6 inches.

Effect of Pressure on Several Lamps

Curves Nos. 1 to 5 are upright lamps, and Nos. 6 and 7 inverted. Nos. 1, 2, 3, 4 and 6 were plotted from results of tests on single burners by L. W. Wild.* Nos. 5 and 7 are American lamps, upright and inverted, respectively, and show a marked difference in performance. The values in Nos. 1 to 6 show the efficiency or duty of these burners in terms of horizontal candle-power per cubic foot of gas per hour. Those in No. 7 are in terms of mean spherical candle-power per cubic foot of gas per hour at pressures from 1.6 inches to 6 inches of water. In the latter curve is shown characteristics of extreme value at all pressures beyond 2 inches, the efficiency increasing with the higher pressures. With No. 6 the point of maximum efficiency is reached at about 1.5 inches; for use exclusively on pressures from 1.3 to 1.7 inches, No. 6 would undoubtedly be the better lamp. Beyond 2 inches, however, this lamp would give very poor results. Curve No. 5, while not ideal by any means, is in marked contrast to Nos. 1 to 4. In the later tests, the lamps were adjusted for maximum intensity at each 0.4 inch change in pressure.

* Journal of Gas Lighting, Vol. 48, 1907, p. 24.

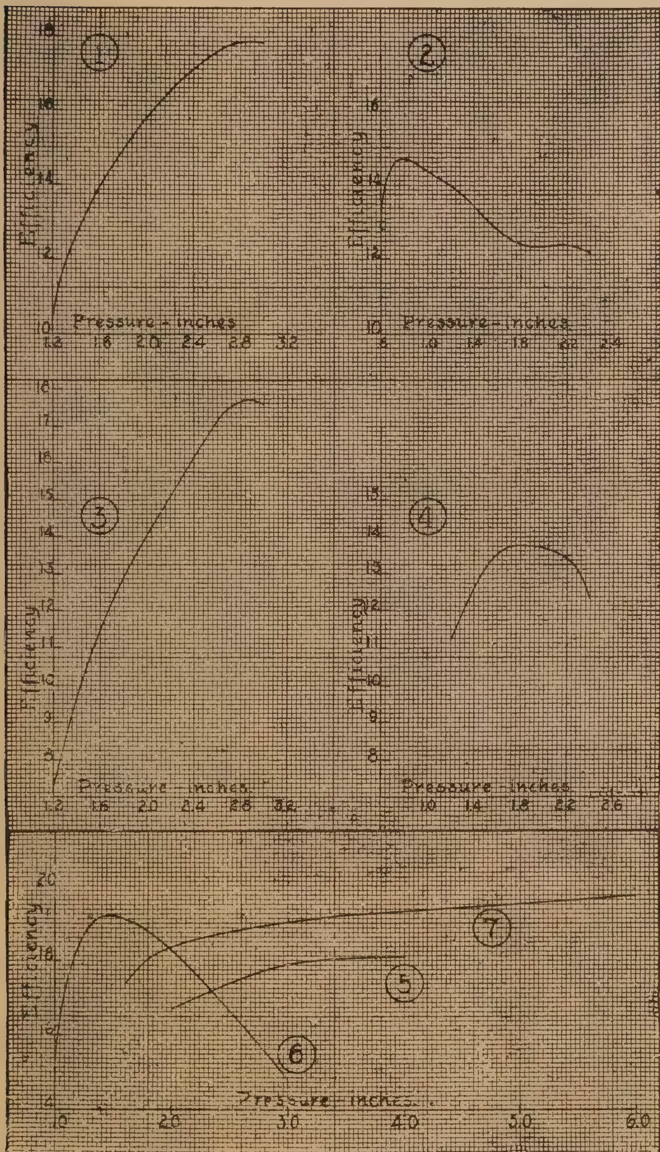

FIG. 2.—Effect of Pressure on Certain Lamps.

Lamp No. 3 shows a duty at 1.3 inches pressure, but 50 per cent of that at 2.8 inches. In fact, any of the lamps represented by Nos. 1, 2, 3, 4 and 6 would show considerable changes in light output with varying pressures.

Tests on American lamps along somewhat similar lines were reported by the writer in papers before the Illuminating Engineering Society and the National Commercial Gas Association.*

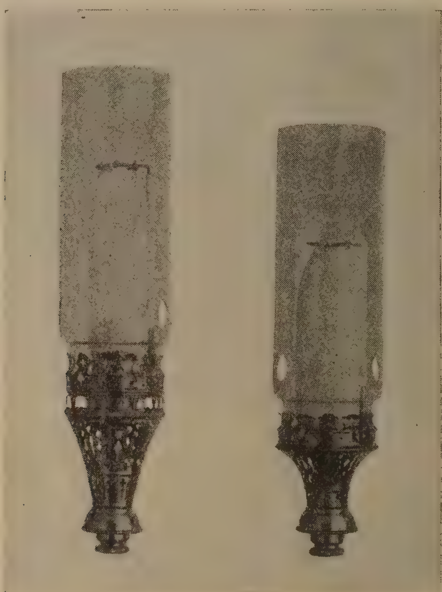

FIG. 3.—Upright Lamps, G and H.

Tests on Upright Lamps

A number of upright burners of each kind illustrated in Figs. 3 and 4, were equipped with cotton mantles of the following sizes, respectively; 4 inches by 1 inch, 3½ inches by 1 inch, 2½ inches by 1 inch, and on the last two lamps shown, 2½ inches by ¾ of an inch. The purpose of these tests was not to show the highest

* The Relation Between Pressure and Light Output with Various Gas Lamps and Burners. Transactions of the Illuminating Engineering Society, Vol. 5, November, 1910, p. 685; and paper on Illumination, National Commercial Gas Association Proceedings, December, 1910.

light output nor maximum efficiency or duty which it might be possible to secure with these lamps, but rather the average results which might be readily reproducible and which would represent as nearly as possible the performance to be expected in practice with a similar commercial product and equipment.

The comparative light output of these lamps may be noted from the distribution curves (Fig. 5) made at 2 inches pressure. From

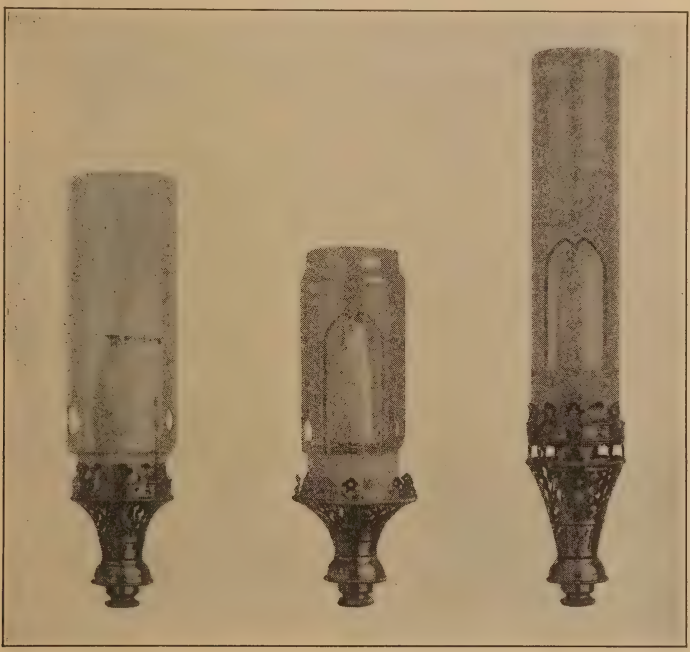

Fig. 4.—Upright Lamps, I, J and J′.

this it would appear that there is no particular advantage in using a 4-inch mantle at this pressure, as both the duty and light output are greater on the 3½-inch mantle.

In Fig. 6 is shown the considerable effect due to pressure. These are the vertical distribution curves of the average of each series of lamps at 2-inch and 8-inch pressures. In Fig. 7 is shown the characteristics of performance of these lamps at all points investigated. These percentage values indicate that these lamps give considerably higher efficiencies when used on pressures of 2 inches or over. It may also be noted by reference to the top part of the

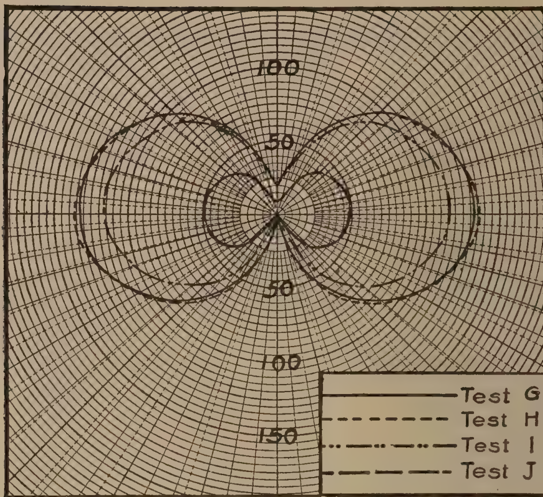

FIG. 5.—Distribution of Light About Four Upright Lamps at 2-inch Pressure.

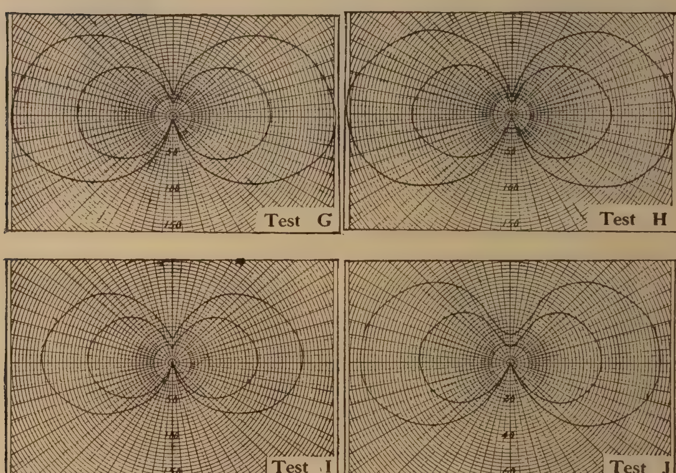

FIG. 6.—Distribution of Light about Upright Lamps at 2-inch and 8-inch Pressures.

diagram (per cent duty) that the various lamps acted quite differently under the different pressures (the horizontal pressure-scale values are 4 squares to the inch, with 2.5 inches pressure as the base); the lamps in series G show the highest efficiencies beyond

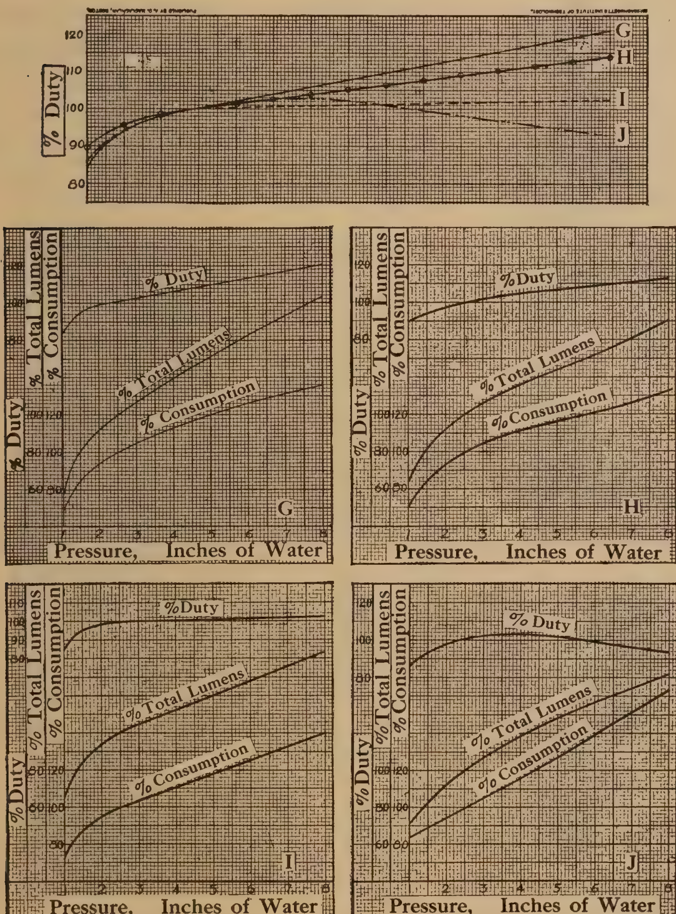

FIG. 7.—Characteristic of Performance of Upright Lamps, with the Base at 2.5-inch Pressure.

the 3-inch pressures, while at 4-inch the J series drops off nearly 8 per cent at the 8-inch pressure. Series I follows an almost ideal straight line from 2½ inches to 8 inches. These results demonstrate that one lamp may meet a certain pressure condition better

than another, also that the general assumption of a higher efficiency with increased pressures may be qualified, and we should not fail to take the burner equipment and gas conditions into consideration.

Importance of Design

A particular lamp equipped as shown in H (Fig. 3) was tested, and then the chimney was changed to one having smaller air holes. This test proved that the slight change in design—using air holes ⅛ of an inch larger in diameter, as in the H test—increased the light output 14 per cent. In Fig. 8 the curve H′ is with a larger air-hole chimney, the inner curve showing the result with a smaller air-hole chimney.

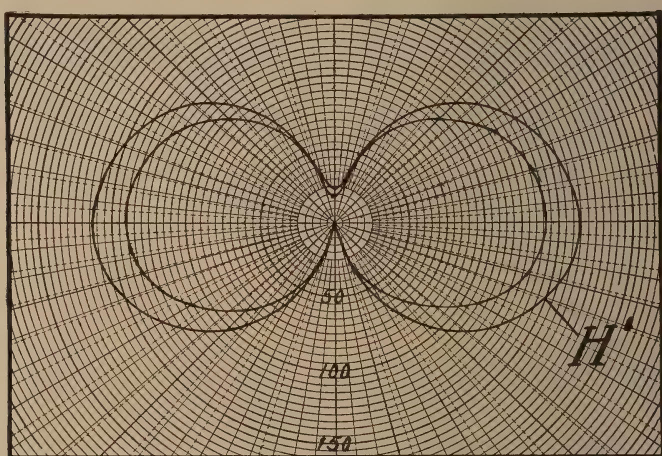

FIG. 8.—Light Distribution about an Upright Lamp with Different Chimneys.

The lamp J′, shown in Fig. 4, was but slightly less efficient than J, having a similar mantle. This lamp did not show quite as high an efficiency or duty as J, but was shown to have an almost straight line efficiency curve at all pressures from 1 to 8 inches.

TABLE NO. 1

RESULTS AT 2.5-INCH PRESSURE WITH UPRIGHT INCANDESCENT LAMPS

Lamps	G	H	I	J
Total lumens per cu. ft. per hour (duty)	204.0	235.0	228.0	212.0
Total lumens	1358.0	1390.0	1156.0	512.0
Consumption cu. ft. per hour	6.64	5.95	5.08	2.41
Horizontal C. P.	140.6	146.5	123.2	52 1

Tests on Inverted Lamps

A somewhat similar series of tests on inverted lamps of the design shown in Fig. 10 prove conclusively that these lamps also have their peculiar characteristics of performance. These tests were

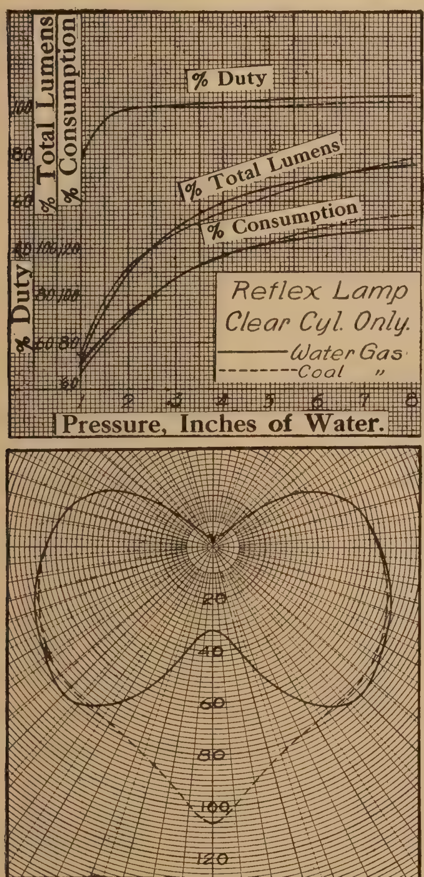

FIG. 9.

FIG. 10.

FIG. 9.—Characteristic of Performance of Inverted Lamps with Base at 2.5-inch Pressure, and Light Distribution Curves with Clear and Frosted Tip Cylinders.
FIG. 10.—Inverted Lamp with Clear Cylinder and Frosted Tip Cylinder.

run on both straight water gas and straight coal gas, and the upper diagram (Fig. 9), considered with Table No. 2, shows the differences due to these two gases when used with the same series of

lamps. In the lower part of diagram (Fig. 9) is given the distribution curves at 2.5-inch pressure of the average of these series of lamps with clear cylinders and with frosted tip cylinders.

TABLE NO. 2

RESULTS AT 2.5-INCH PRESSURE WITH INVERTED LAMPS, WITH CLEAR CYLINDERS

	Water Gas	Coal Gas	% $\frac{\text{Coal Gas}}{\text{Water Gas}}$
Total lumens per cu. ft. per hour (duty)	205.8	171.5	83.4
Total lumens	687.0	638.3	93.0
Consumption	3.34	3.72	111.5

The water gas used in these tests averaged 19.8 candle-power, having a calorific value of 620 B. t. u. and a specific gravity of 0.66; while the coal gas was 13.24 candle-power, 540 B. t. u., 0.55 specific gravity.

This series of tests shows rather conclusively that reports on the light output and gas consumption on different lamps at different pressures may in no way be considered comparable unless the characteristics of performance of each lamp is known at the various other pressures. And without this information the distribution of light about a particular lamp at a given pressure may be of little value unless that particular lamp is to be used in service at a similar pressure.

In Fig. 11 is shown the average distribution of light about the series of inverted lamps with clear cylinders tested on water gas at 2-inch, 2½-inch, 3-inch, 4-inch, 5-inch, 6-inch, 7-inch and 8-inch pressures. In this series of tests it was found that horizontal readings of the intensity from lamps equipped with clear cylinders were not representative of the total light flux as was the case with upright burners. The candle-power readings on the horizontal did not bear any definite relation to the total flux of light produced at the various pressures. It was found, however, that the intensity at 77° 30′ was not only a definite proportion of the total flux, varying as the total flux varied, but it also happened that the candle-power at this angle when multiplied by 10 gave as a result the total flux from this lamp in lumens.

Rating Lamps

All light sources should be rated in terms of their total flux, and considerable confusion, to say the least, has resulted in rating them

otherwise. This has been covered very clearly by Dr. C. P. Steinmetz,* "Only the mean spherical intensity—which represents the total flux of light—and the distribution curve—which represents the distribution of this light in space—are of importance. The 'horizontal intensity' has been used as a conventional rating of incandescent lamps, but is merely fictitious, as it does not mean an actual average horizontal intensity, but the horizontal intensity

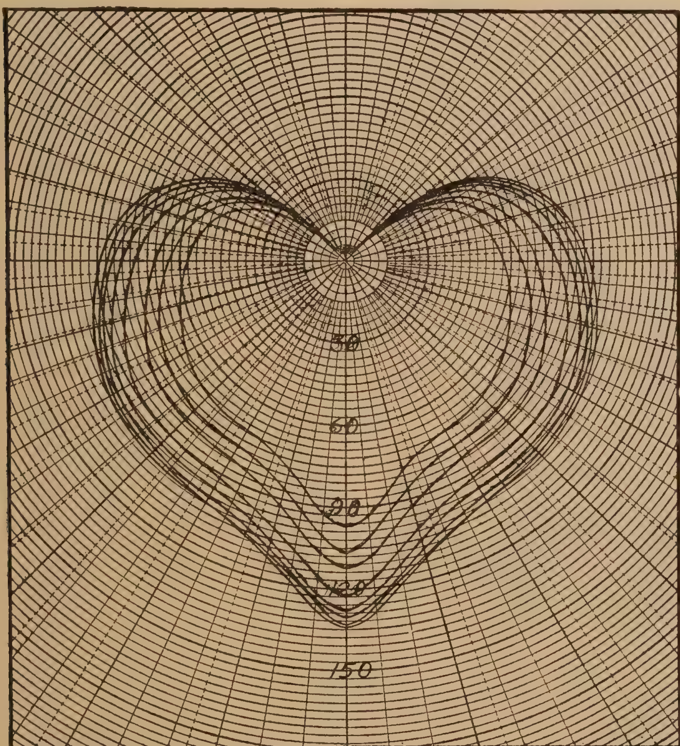

FIG. 11.—Distribution of Light about an Inverted Lamp at Various Pressures, 2.5 inches to 8 inches.

which the light flux of this lamp would give with the standard mean spherical reduction factor, if the filament had the standard shape.

"Downward candle-power and maximum candle-power obviously have no meaning regarding the light flux of the lamp, but merely represent a particular feature of the distribution curve.

* Radiation, Light and Illumination, p. 184, par. 85.

"Hemispherical candle-power is used to some extent, especially abroad. It is a mixture between light flux and distribution curve, and as it gives no information on the total light flux, nor on the actual distribution curve, and may mislead to attribute to the lamp a greater light flux than it possesses—by mistaking it with mean spherical candle-power—it has no excuse for existence, and should not be used."

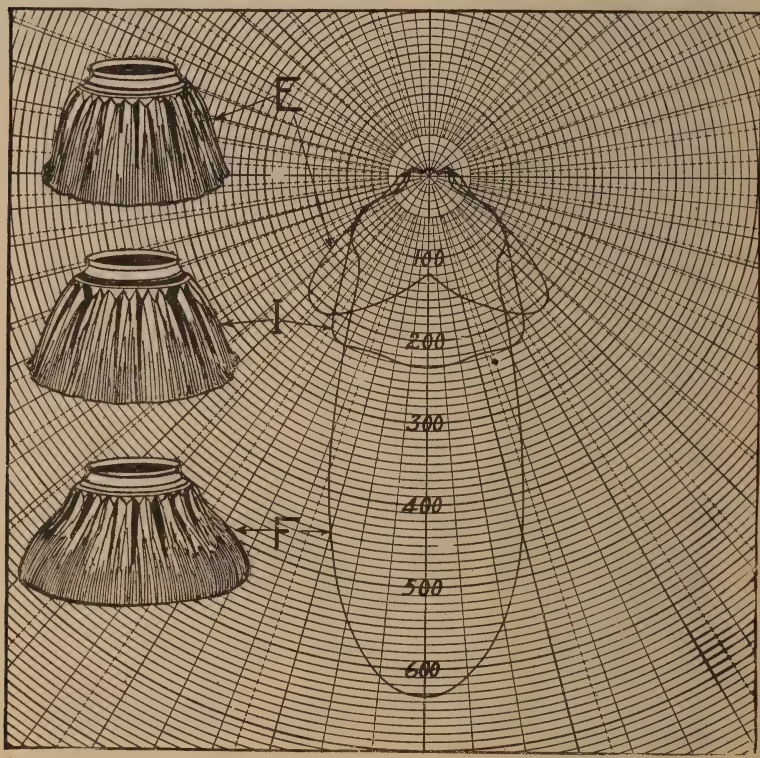

FIG. 12.—Distribution of Light about an Inverted Lamp with Three Different Reflectors.

What Polar Curves Represent

That a statement of the total flux from a lamp is alone not sufficient—that a mention of the maximum candle-power is valueless, and that a casual consideration of a distribution curve is likely to be highly misleading—may be assumed from the three distribution curves in Fig. 12, which represent the characteristic ex-

tensive, intensive and focusing types of light distribution secured from one particular lamp equipped with each one of the prismatic reflectors illustrated.

The total flux differences are very slight, indeed, and are effected by the slight differences in shape or depth of the reflectors. The "F" curve represents slightly less total flux than does either the "E" or "I" curves. The maximum candle-power values of 210, 230 or 635 can certainly not be used in efficiency statements, where they would have the effect of crediting a lamp, which has an actual efficiency of 16 to 17 mean spherical candle-power per cubic foot per hour, with an output of 63.5, 69.5 or 192 candle-power per cubic foot per hour, and yet similar ratings have been made, and in certain quarters, even in some trade journals, examples may be found at the present time.

While attention has been frequently called to the fact that the polar diagram, as a graphic representation of *quantity* of light, has no significance, and this fact should be sufficiently understood by those having even an elementary knowledge of the use of the graphic method of representing relations between variables, there are still many cases in which the polar diagram is assumed to represent the amount of light. This is really a most natural inference to make, since it is the surface included by the curve rather than the curved line itself that naturally first impresses one.

The polar diagram shows only the radiant intensities and does not, therefore, correctly indicate the change in flux of light at various angles. The apparent discrepancy in the areas comes from the fact that with polar curves a comparatively small expansion in the zone about the horizontal plane is equivalent to a considerable expansion in the zone about the vertical axis. The zone 2° below the horizontal represents an area equal to that of the 15° zone about the vertical axis. For the purpose of representing the actual intensities at the various angles, and giving at once a general idea of the light distribution, the polar curves are necessary and desirable.

Photometric Limitations

It is also important in all photometric tests of gas lamps, as with electric lamps, to know the distance from the photometer screen to the source. With many large sources mistakes have been made by assuming a distance from which the source could not be considered as a theoretical point source. Many special fixtures, large

units, and especially those units having an asymmetrical distribution, should be investigated with an illuminometer or illumination photometer, for the various heights at which these units are to be used, and throughout those points on the plane where the illumination would be effective. This point was brought up by the writer in a paper before the Illuminating Engineering Society Convention in 1909.* It was there shown, by measurements from a four-light fixture, having an over-all dimension of 24 inches, that the difference in apparent flux with the illuminometer test plate on a horizontal plane and a fixture height of 4 feet, and also at 8 feet, might be as great as 22 per cent. The greater differences were shown to be on planes when the source was at "heights" within 6 feet.

When we consider, however, that many units on the greater number of installations are used for the illumination of planes with "heights" at from 6 inches to 6 feet, it will possibly be realized that this point is one of importance. It might be here noted that the possibility of deviation from the cosine law of the test plate on the illuminometer was provided for by taking all measurements normal and reducing same to horizontal values by calculation. For accurate calculation, it may therefore be assumed that best results can be secured from an illuminometer investigation of an average lamp similar to that which it is proposed to use in the installation, at the different heights at which the radiant may be placed and at various points on the plane at such distances within which the light would be effective.

Photometric Curves of Gas Lamps

Generally speaking, however, the usual photometric curve may be used if it is considered as being merely representative of the distribution characteristics of that radiant. Point to point calculations may then be made with the sole idea of uniformity or ununiformity, as may be desired, using the candle-power values merely as proportional values, and depending upon either illuminometer measurements, as above explained, or upon the "experience factors," lumens per cubic foot of gas, of the various units under consideration.

With the many kinds of gas lamps, reflectors and other accessories now on the market, practically any distribution of light may

* Some Results Obtained Through Illuminometry, Transactions of the Illuminating Engineering Society, Vol. 4, p. 789.

be secured. In Fig. 5 is illustrated the characteristic distribution curves of single upright-mantle lamps, and in Fig. 9 the distribution from a single inverted-mantle with clear cylinder, and also a frosted-tip cylinder, while in Fig. 13 is shown the characteristic distribution curves of the multiple inverted-mantle lamps, commonly known as "inverted arcs." These curves are of three-, four- and five-mantle lamps of various manufacture, and are not materially different in their characteristics to that of the single inverted-mantle lamp. In Fig. 14 is shown the light distribution from

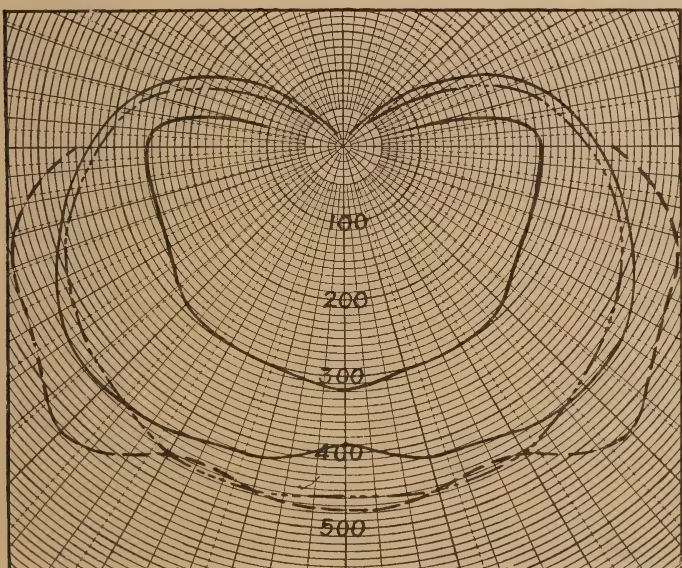

FIG. 13.—Characteristic Distribution of Light about Multiple Inverted Mantle Lamps. (Inverted Arcs.)

upright-mantle sources; on the right, an upright-mantle arc with opal reflector, and on the left, a single upright-mantle lamp with a "Q" chimney.

The distribution of light about an upright arc without a reflector is quite similar to this curve on the left, the apparent candle-power of which was here changed one to four to enable a comparison to be more readily made. These lamps, as required by their distribution characteristics, are usually hung quite low, and should, therefore, without exception, be equipped with opal or light-diffus-

ing globes. Sources of high specific intensity should be placed well out of the field of vision. While incandescent mantles undoubtedly have a much lower specific intensity than incandescent lamp filaments, the intensity is still too high to permit the installation of unscreened mantles in locations where they will come within the field of view. Reducing the intensity of a source by surrounding same with an opal or sand-blasted globe enables us to see with more comfort, and actually to see more clearly, owing to the well-known effect of the eye working with a larger pupillary

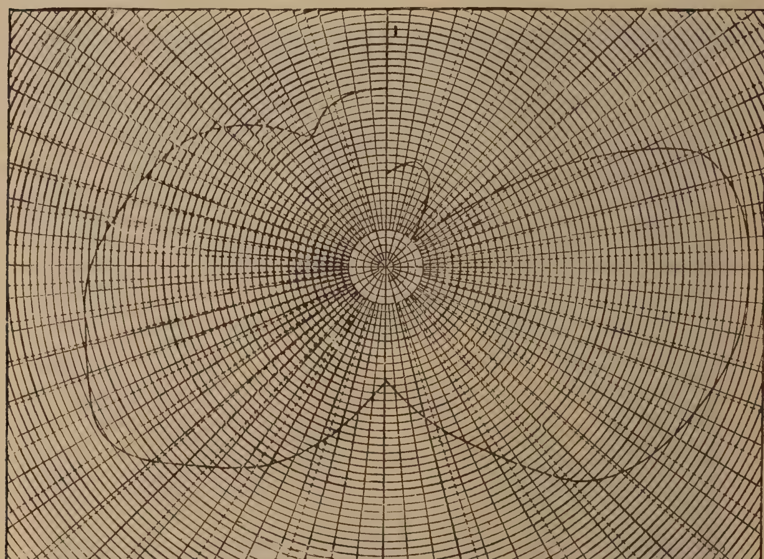

FIG. 14.—Characteristic Distribution of Light about Upright Lamps.

opening in the absence of glare. This is a point of particular importance with multiple-mantle lamps when enclosed within a globe.

The Use of Clear Globes

Experience and repeated experiments prove conclusively that clear globes interfere with clear vision. It is a common mistake to think that the more light we have the better we can see. There could hardly be a greater error. A source of high specific intensity within the field of vision tends to defeat its own purpose as an illuminant by automatically stopping down the iris. A practical appreciation of this condition is given in many towns where ordi-

nances have been passed requiring saloons to take down all screens and blinds from the windows that those on the street could readily see into the room. In many places the letter of the law was upheld, but the spirit was violated by having arc lamps with clear globes installed in the windows. Of course, these lamps were nominally used for window lighting, and not as screens, within the letter of the law, but they were, nevertheless, successful as screens.

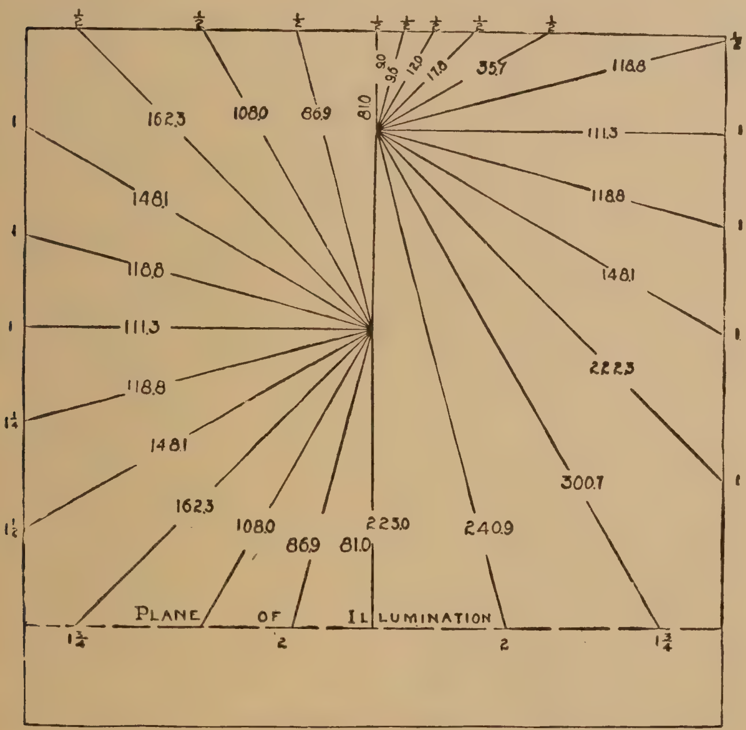

FIG. 15.—Diagram of Elevation of a Room.

The varied problems presented in practical illumination work require many different kinds of lamps having widely different characteristics of light distribution. Before the introduction of inverted lamps, when the upright lamps were practically the only sources available, the various distributions were secured, either by absorbing the excess of light in those directions where it was not wanted, or by means of various reflectors redirecting the light rays into the useful zones. As good engineering is along economical

lines, rather than those which may be wasteful, the inverted lamp was found to fill a very necessary field. This is shown graphically in Figs. 15 and 16. Fig. 15 is an elevation of a room 14 feet high and 14 feet wide, with the "plane of illumination" 2 feet above the floor. For a source suspended 6 feet above the plane (8 feet above the floor) the comparative intensities are shown on

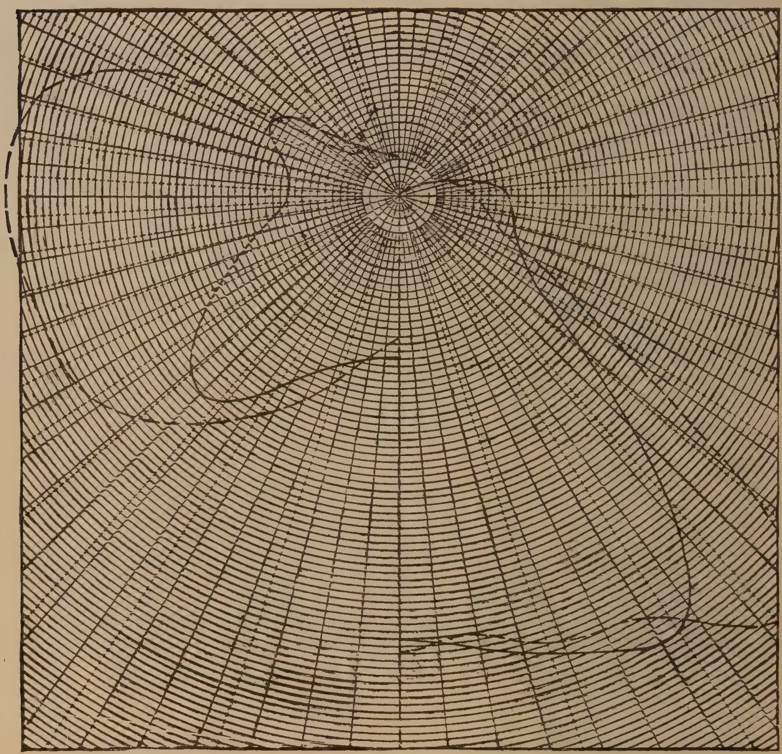

FIG. 16.—Actual and Specification Curves of Upright and Inverted Mantle Sources.

the left for uniform normal illumination on the plane, walls and ceiling. On the right are shown corresponding values for a source 10 feet above the plane. The values here given are merely the squares of these distances, as measured with some convenient scale, and as such represent the proportionate intensity values for normal illumination of equal intensity at these points.

The Illumination of Walls and Ceilings

The illumination of walls and ceiling is desirable and sometimes necessary, but rarely in mercantile establishments to an intensity exceeding 1 foot-candle. The intensity on the walls should rarely exceed one-fifth to one-third of the illumination on the important plane, counters, etc., where goods may be subjected to close or critical examination. The general effect of a high and uniform intensity on the walls is a demand for a higher intensity on the useful plane. Upright-mantle arc lamps illuminate the walls of the average store, where such lamps are used, to a higher intensity than the counters, with the lamp hung 8 feet above the floor; this is also true of an inverted arc having the typical distribution shown in Fig. 13, when used at heights of 10 feet or more.

The intensity on the walls may and should be less than that in the lower portion of the room. We desire only sufficient light to illuminate the wall fixtures or shelving, and this may properly be one-quarter of the maximum on the plane. A brightly illuminated wall, through its effect on the eye, necessitates a higher intensity throughout the room where the light is required for close discernment of objects or goods, thereby reducing the efficiency of the installation as a whole. Therefore, assuming that a uniform intensity of illumination on the plane, walls and ceiling is not desirable, the proportions were modified, as shown by the marginal notations (Fig. 15), i. e., two units on the plane to one-half on the ceiling and one on the upper side walls. The solid-line curves in Fig. 16 show this relation. The dotted curve on the left is a distribution curve of an upright multiple-mantle lamp, while that on the right is that of an inverted-mantle source equipped with a prismatic reflector. A comparison of these curves gives a fair idea of the distribution efficiencies of these two sources. The enormous amount of light in excess of that required, in the zone 30° above and 30° below the horizontal, which is dependent upon the low coefficient of reflection of walls or shelving on which dark goods may be displayed, would insure only a small percentage of this light ever reaching the working plane, which accounts in a large measure for the increased efficiency of the more modern inverted-lamp equipment over that of the upright.

It should be noted that by suspending the inverted-mantle source higher than the upright, the intensities on the walls and ceiling

may be sufficient and in proper proportion to that on the plane. Inverted lamps, therefore, have that favorable downward distribution of light which admits of their being placed at heights greatly exceeding that possible with upright-mantle sources.

Reflectors on Inverted Lamps

The reflectors and shades used on single mantle-inverted lamps also successfully screen the mantle from direct vision, excepting from directly below the lamp, a position from which one is not at all likely to observe them. This advantage is secured with a very small light-absorption loss, and the effective illumination is greatly increased by the redirected light which otherwise has been largely wasted upon the walls or fronts of shelving.

When it is considered that this light, which is directed on and above the horizontal from a lamp, must be reflected from the average ceiling and wall, or from the various colored goods displayed upon the shelving, several times before reaching the lower part of the room, with a considerable absorption of the light for each reflection, consideration of a few of the absorption factors of ordinary colored papers is interesting and instructive.

TABLE NO. 3*

Papers	Absorption Factors
Ordinary foolscap paper	30%
Orange paper	50
Yellow wall-paper	60
Light pink paper	64
Light blue paper	75
Brown	80
Blue-green paper	88
Deep chocolate	96

Absorption of Light Problems

Take yellow wall paper as an example, and consider an upright-mantle arc with a reflector, generating 2500 lumens, approximately 40 per cent of which (in round numbers 160 mean upper hemispherical candle-power or 1000 lumens) is directed to the upper hemisphere. Assuming that this flux of light is toward that part of the room from which at least three reflections would be necessary before reaching the useful plane, the result would be as follows:

1000 less 60% = 400, after first reflection.
400 less 60% = 160, after two reflections.
160 less 60% = 64 lumens after three reflections.

* Dr. W. E. Sumpner, Phil. Magazine, February, 1893, p. 81, and Art of Illumination, Dr. Louis Bell, p. 52.

The net contribution to the useful plane with only three reflections would be 64 lumens, 6.4 per cent of the upper hemispherical flux, or $2\frac{1}{2}$ per cent of the total light flux generated by this one lamp; and it is this $2\frac{1}{2}$ per cent which some writers have referred to as of "extreme importance" in adding to the uniformity of the illumination where this lamp has been used. This method of obtaining a uniformity of distribution of light cannot be other than extremely inefficient and costly.

It is frequently desirable to determine by calculation just what proportion of the light from a particular source in a certain location will be effective on the plane, and a calculation somewhat similar to that given above would be desirable. This is ordinarily known as the "Absorption-of-Light" method of calculation.*

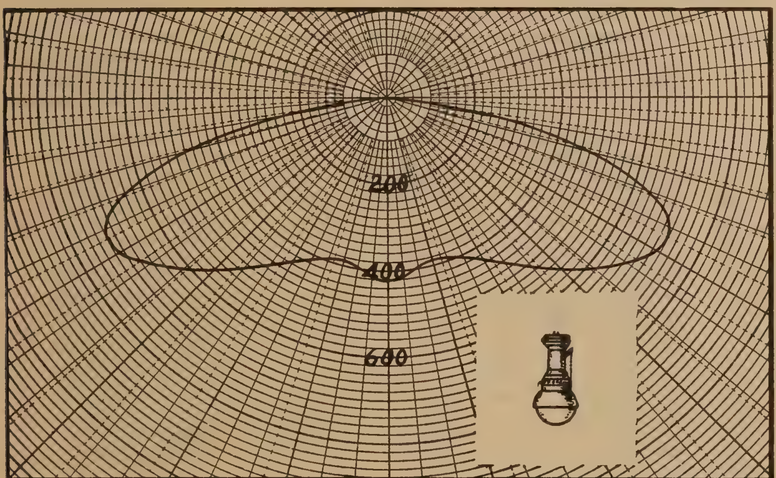

FIG. 17.—Light Distribution about an Inverted Arc Equipped with a Reflector.

Upright-arc lamps have an extensive field in the illumination of large interiors where a wide distribution and large units may be used to advantage, and a comparatively low intensity is frequently desirable. Warehouses, armories, large auditoriums and many classes of exterior illumination afford opportunities for these lamps.

In Fig. 17 is shown a fairly efficient light distribution from a multiple inverted-mantle lamp equipped with a reflector. This is

* Dr. A. S. McAllister, Electrical World, Vol. LIII, Nov. 21, 1908, p. 1128, and LV, May 26, 1910, pp. 1362 and 1389.

a most excellent distribution for comparatively large areas, which will result in practically uniform illumination with outlets at distances equal to nearly three times the height of the radiant above the plane.

Life of Mantles

It might be well at this point to insert a statement on the life of mantles and their depreciation.

The laboratory life tests show that the cheap upright mantles have a life of from 200 to 400 hours, while the better grade average 800 to 1500 hours. These cheap mantles will fall off fully 50 per

MACBETH ILLUMINATION DATA FORM 24

CALCULATED BY R.W.K. ASSESSORIES Welsbach Holophane #6321.
CHECKED BY R.W.K. SOURCE OF LIGHT Reflex--clear cylinder. I_h
DATE 2-15-09 PHOTOMETRIC DATA BY E.T.L. PLATE NO 2808.

INTENSITY & FLUX	5'-0"	6'-0"	7'-0"	8'-0"	8'-6"	9'-0"	9'-6"	10'-0"	11'-0"	12'-0"	DIST
Jo 51.7	6.20	4.29	3.15	2.39	2.13	1.90	1.70	1.54	1.28	1.08	0
Lm. 649.3	5.73	4.00	2.97	2.29	2.04	1.83	1.635	1.52	1.24	1.05	1
Jo 10.6	5.16	3.78	2.83	2.20	1.96	1.76	1.57	1.44	1.21	1.01	2
Lm. 66.6	4.21	3.2-	2.56	2.06	1.86	1.69	1.52	1.38	1.16	.99	3
Jo 92.8	3.55	2.74	2.19	1.81	1.66	1.53	1.40	1.28	1.10	.95	4
Lm. 582.7	2.68	2.37	1.96	1.60	1.48	1.36	1.265	1.18	1.01	.88	5
ZONE 0°-75°	1.57	1.86	1.69	1.45	1.34	1.22	1.14	1.05	.915	.801	6
Jo 115.3	.730	1.21	1.37	1.26	1.19+	1.12	1.045	.97	.845	.726	7
Lm. 536	.471	.711	.95	1.05	1.01	.973	.915	.89	.78	.684	8
ZONE 0°-60°	.269	.427	.60	.720	.831	.828	.810	.781	.718	.644	9
Jo 181	.172	.286	.348	.450	.59-	.627	.676	.669	.63	.594	10
Lm 474	.093	.119	.170	.240	.273	.317	.354	.392	.485	.463	12
ZONE 0°-45°	.053	.067	.088	.143	.148	.174	.288	.183	.26	.30	14
Jo 169.9	.035	.051	.055	.067	.081	.094	.107	.118	.148	.177	16
Lm. 312.6	.024	.030	.036	.043	.048	.058	.061	.068	.092	.107	18
ZONE 0°-30°	.017	.022	.026	.030	.033	.037	.039	.043	.055	.071	20
Jo 79.1		.016	.020	.022	.024	.027	.029	.031	.035	.045	22
Lm. 133.2		.012	.015	.017	.018	.020	.021	.023	.026	.03	24
ZONE 0°-20°			.012	.013	.014	.015	.016	.018	.020	.022	26
Jo 158.2			.009	.010	.011	.012	.013	.013	.015	.016	28
Lm. 58.1				.008	.009	.009	.010	.011	.012	.013	30

FIG. 18.—Data Sheet.

cent in light output, while the better quality will show a depreciation of upwards to 30 per cent in 1000 to 1500 hours.

In the inverted mantles the cheap grades last from 500 to 1000 hours with a 20 per cent drop in 500 hours. The better quality inverted mantles will show a life of from 2500 to 8000 hours, with a light depreciation not exceeding 10 per cent in 1000 hours, and rarely over 10 per cent with the artificial silk mantles even in 8000 hours.

Lamps in service to maintain these figures should be under maintenance, as in the presence of considerable dust, careless or no maintenance, the effective life of mantles and their ability to give good service is much curtailed. Lamps which are not in use or

which may not be lighted at least 5 minutes a week will depreciate more rapidly. The latter is especially true for the summer months in those localities where the humidity is high.

Point-to-Point Calculations

As a matter of simplifying the work on plans and installations, the writer has always found it convenient to fill out a form similar to that shown in Fig. 18, working out the horizontal illumination values at all points from immediately below the source and for 1-foot distances up to 10 feet, and 2-foot distances to 30 feet, for the various heights at which this particular unit is likely to be used, noting also the total flux values, the upper and lower hemisphere and the various zonular values required at different times. This facilitates the getting out of work by either the point to point or flux method of calculation.

In Fig. 19 is shown the plan and elevation for the illumination of a sewing-machine work-table. Work of this kind would come under the "point to point" method of calculation, as it is desirable to know just what intensity would be effective on the plane where the maximum illumination is required, i. e., at the needle. In the elevation drawing is shown the relative height of the lamp, which should be such that a line drawn from the lowest position of the operator's eye to the edge of the opaque reflector, when extended will be below the mantle, thus insuring a lamp position with the mantle safely removed from the field of view. Where it is desired to take care of the general illumination also with the same lamps, translucent reflectors may be used, in which event the height should be increased. The use of an illuminometer will be found very helpful in this kind of work, and investigations of satisfactory installations will show intensities in some cases of upwards to 100 foot-candles, which, when confined to a small area, with operators on fine work on dark goods, may not be excessive.

Bowling-Alley Problems

An illuminometer is practically a necessity as an aid in determining the best arrangement of lamps for bowling-alley illumination. A consideration of the requirements, that the illumination shall be uniform down the entire length of the alley with the mantles or other sources of higher specific intensity removed from the line of vision of the bowler; that all direct reflection spots

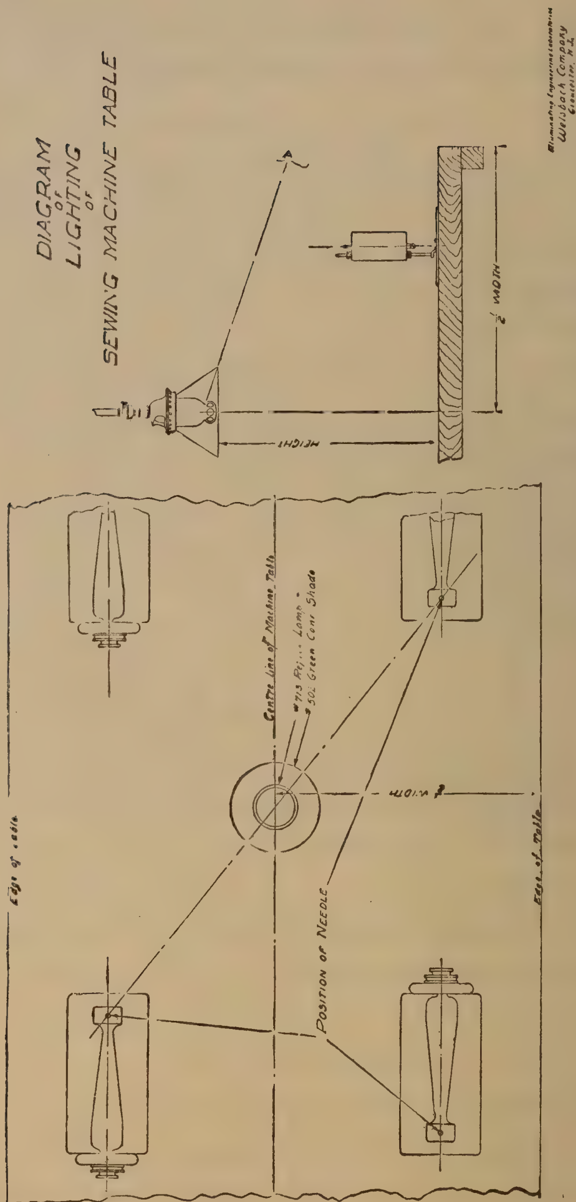

FIG. 19.—Arrangement of Lamps for Work-table Illumination.

on the surface of the alley shall be obviated, that finally the bowler may be enabled to see with ease and comfort each and every pin strongly outlined and fully defined against the dark background at the rear of the pit.

The above requirements can best be met with an angle reflector having a similar distribution to that shown in Fig. 20. The curve

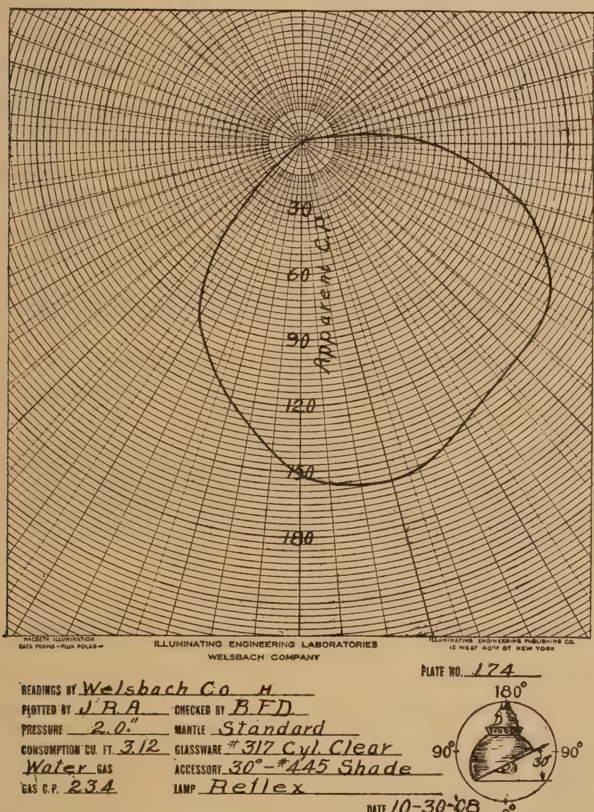

FIG. 20.—Light Distribution about an Inverted Lamp with Angle Reflector.

shown is the light distribution in the vertical plane only, and could be used for calculating the intensities on the horizontal plane for a narrow band in the projection normal to the opening in the reflector which would in a double alley be along the unimportant rack on which the balls are returned from the pit to the player. The important plane, that effective on the center of the alleys, could

with difficulty be investigated on the ordinary radial photometer, and the results so secured would be of little value for purposes of calculation, because of the lengthy and intricate calculations involved.

To hang up a lamp equipped with the proper reflector and take measurements in the various effective planes is a comparatively simple problem, and permits the securing of results which may be directly and easily applied to the design of bowling-alley illumination using one row of lamps for either a single or a double-alley, or two rows of lamps for a set of three alleys. A satisfactory method of installation is shown in Fig. 21.

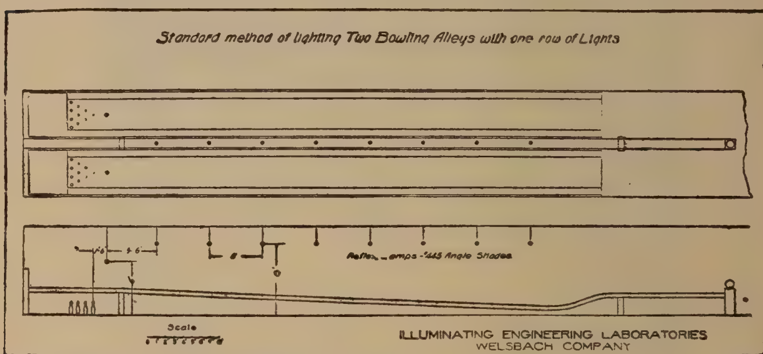

FIG. 21.—Bowling Alley Plan.

Post-Office Problems

In Fig. 22 is shown a problem in post-office illumination on the carriers' sorting tables. In this work the position of the lamp and the direction of the light is all important. A normal calculation will show that the resultant intensity of illumination from the single inverted-mantle lamps at present on the market will be ample at all points where the carrier requires a sufficient amount of illumination to rapidly decipher the superscriptions on the mail being sorted.

Fig. 23 illustrates a somewhat similar problem, and in this location, especially, smaller lamps could be used. It is necessary, however, to install four lamps as here shown to insure a proper direction of light that the operator working at these files may at all times have sufficient illumination on his work, while at the same time he would be free from direct reflection and other objectionable features present if but one or two lamps were used.

Distributed Unit System

In Fig. 24 is illustrated a system for uniform illumination from distributed units. The requirements in this room necessitate the placing of a lamp in a particular position; and either a point to point calculation or a flux calculation may be used to determine the approximate size of lamps to be used.

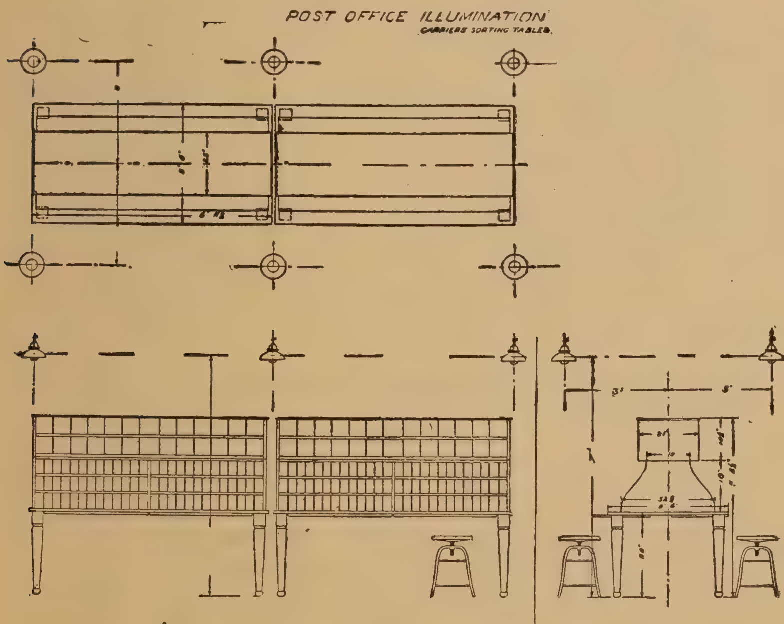

FIG. 22.—Detail of Carriers' Tables.

Use of Experience Factors

In many problems where it is largely a matter of general illumination in contradistinction to localized or concentrated illumination, the problem may be taken care of with calculations based on "experience factors." With these experience factors, due allowance has been made for the practical conditions of installations, and the many considerations in actual installations due to variation in the commercial product. By illuminometer and physical measurements made on actual installations, an analysis is possible, the results of which may be checked with diagrams similar to Figs. 7 and 9, and factors determined which will at least represent an average or minimum reproducible value. Such factors are shown in Table No. 4.

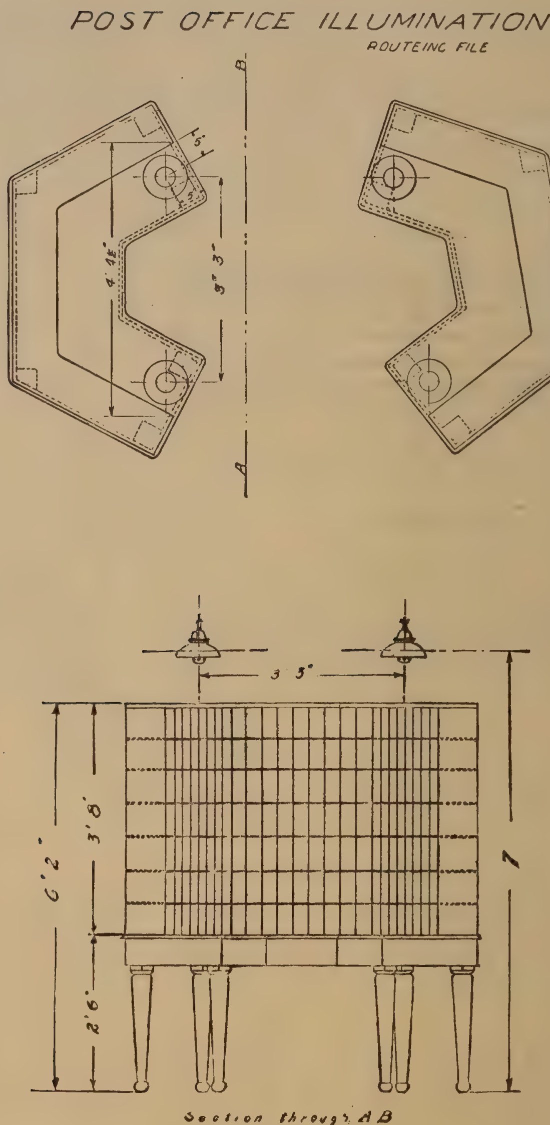

FIG. 23.—Detail of Routeing Files.

TABLE NO. 4

Lighting Unit	Nominal consumption of unit cu. ft. per hour	Factors. Lumens per cu. ft. of gas per hour light ceiling — With light walls	With dark walls
Inverted lamps with frosted tip cylinders, prismatic or light opal concentrating reflectors	3⅓	125	114
Inverted lamps with frosted tip cylinders, prismatic or light opal distributing reflectors	3⅓	110	100
Inverted lamps with frosted tip cylinders, French roughed ball globes	3⅓	95	70
Inverted cluster lamp, four-mantle, with alabaster globe	13	85	64
Inverted five-mantle arc with alabaster globe	16.6	87	65
Upright four-mantle arc with opal reflector and alabaster globe	20	75	55
Upright four-mantle arc with alabaster globe only	20	66	48

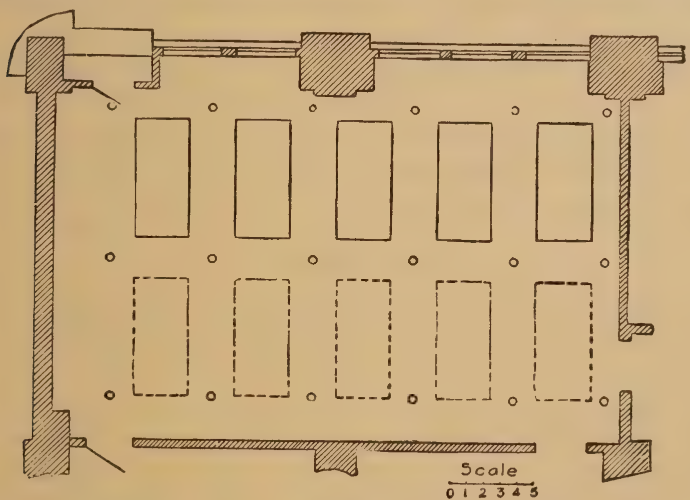

FIG. 24.—Arrangement of Outlets for Distributed Unit System.

It has been largely customary, in the absence of more definite information, to use tables more or less extended, similar to that given as Table No. 5, as a basis for calculation in determining the intensity of illumination desired, with Table No. 4 giving the factor for effective lumens per cubic foot of gas per hour to approximate the cubic feet of gas and number of units required to secure a desired intensity with the equipment selected.

TABLE NO. 5

	Class of Service	Illumination in foot-candles*
1	Storerooms, warehouses, etc.	0.5 to 1.5
2	Corridors	0.5 to 1.5
3.	Auditoriums	1 to 3
4	Residence and reading rooms	1 to 3
5	Churches	1.5 to 3
6	Stores—light goods	1 to 3
7	Stores—medium or dark goods	4 to 7
8	Clothing stores	4 to 7
9	Draughting rooms	5 to 10
10	Detail work tables	5 to 15
11	Show windows	10 to 50

* Exact figures cannot be given owing to the variable ideas of the average consumer and differences in the local standards.

To determine the number of lamps required, it is necessary first to find the cubic feet of gas per hour by multiplying the area in square feet under consideration by the illumination in foot-candles required (Table No. 5). From this can be secured the total lumens to be delivered on the horizontal plane. This amount, then, divided by the factor, "lumens per cubic foot," gives as a result the cubic feet of gas per hour. Then the cubic feet of gas per hour, divided by the "nominal consumption of unit," will give the number of lamps or lighting units required.

Spacing of Outlets

From a consideration of the distribution characteristics of the sources used in tables of this kind, simple spacing rules are formulated.

In large rooms inverted lamps with reflectors on single or multiple lamp fixtures should be suspended from 7 to 17 feet above the plane, or approximately 9 to 18 feet above the floor, with the distances between outlets not exceeding one and two-third times the height of the lamps to mantle centers *above the plane*. With fixed outlets, the height to mantle centers above the plane should be three-fifths of the distance between outlet centers. With roughed or opal balls, the height should be slightly less than with reflectors, and the distance may be extended, but should not exceed twice the height. In rooms with low ceilings, single-lamp units may be required with proportionate distances apart, as given above.

Inverted-arc lamps having the characteristic light distribution shown in Fig. 13 should be suspended not lower than 7 feet above the plane, and the distances between outlets should not exceed two times the height *above the plane.*

Upright-mantle arc lamps should not be lower than 6 feet above the plane or 7 to 9 feet above the floor, with distances between outlets not exceeding three times the height *above the plane.*

The above tables, supplemented by experience in placing lamps, will give results more satisfactory than can be secured through any method at all approaching this in directness, and with a minimum expenditure of effort.

The most satisfactory way to solve an illumination problem is to work from a plan of the room or area to be considered. This area may be divided into squares, bays or sections of regular or irregular size, as may be necessary, and any special section can then be given an individual treatment, increased or reduced intensities, according to the character of the goods displayed or the purpose for which the illumination is desired. The size of the units to use and the proper placing of same is largely a matter of experience and judgment.

Architectural Considerations

Architectural or structural features must be given due consideration in deciding the question of size.

The height of the lighting units from the floor is another general problem which must be approached from the standpoints of both efficiency and appearance. The position of units with reference to the ceiling also affects the apparent height of the ceiling itself. A brightly illuminated ceiling will appear to be at a less height than a darker ceiling which is illuminated with a lower intensity.

The position of the unit should also bear a certain proportion to the entire distance from ceiling to floor, rather than be located in strict accordance with the mathematical laws of distribution or efficiency. Thus, in a room with an unusually high ceiling, such as a church, the units or fixtures, if dropped to the position which would be most advantageous from the mathematical standpoint, might give a general effect of disproportion structurally, i. e., would be out of keeping with the general structural features of the building. The same would hold true also if the fixtures were placed comparatively near the ceiling.

The proper height at which to hang lamps and fixtures is largely governed by the requirements of the room under consideration. As a general conclusion, however, inverted-mantle units especially should be placed at greater heights than has been customary with the upright-mantle sources in order best to take advantage of the favorable light distribution of this source, also to protect the eye against glare and the unsatisfactory effects so prevalent with the upright-mantle sources, which, because of their distribution characteristics, must usually be suspended much too low for effective illumination.

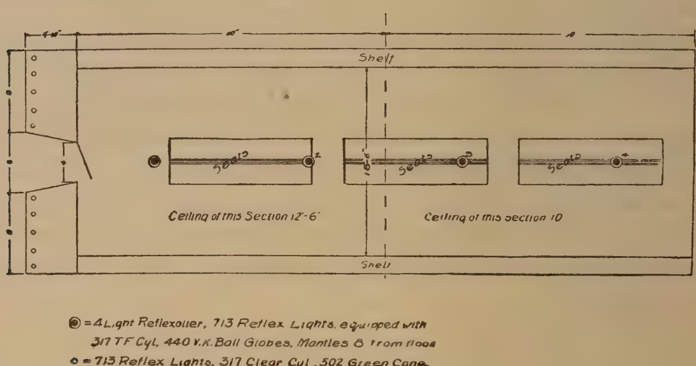

FIG. 25.—Plan of Shoe Store.

A Shoe-Store Problem

Assuming a shoe store (Fig. 25) in which an intensity of about 4 foot-candles would be required—light ceiling and light walls. This store is 60 feet long by 18 feet 6 inches wide between shelving, with a ceiling height in the rear section of 10 feet. Were it desired to use the inverted lamps equipped with sand-blasted balls (Fig. 26), which would insure a better distribution of light with this low ceiling than would be the case with lamps equipped with reflectors (Fig. 27), the factor as given in the table would be 95 lumens per cubic foot of gas. The area of this room, 60 feet by 18 feet 6 inches, would be 1110 square feet. Therefore, $\frac{110\times4}{95}=46.7$ cubic feet, and the number of lamps required, $\frac{46.7}{3.3}=14$. The width of this store is approximately 18 feet, which would not be too great a distance to be taken care of with a single row of

outlets. Outlets at distances apart equal to the width of the store—18 feet—would not divide up satisfactorily into the 60-foot length. Four outlets 15 feet apart $\left(\frac{60}{4}=15\right)$ would be much better than three outlets at 20-foot distances. The distance from the end outlet to the end of the store should be about one-half the distance

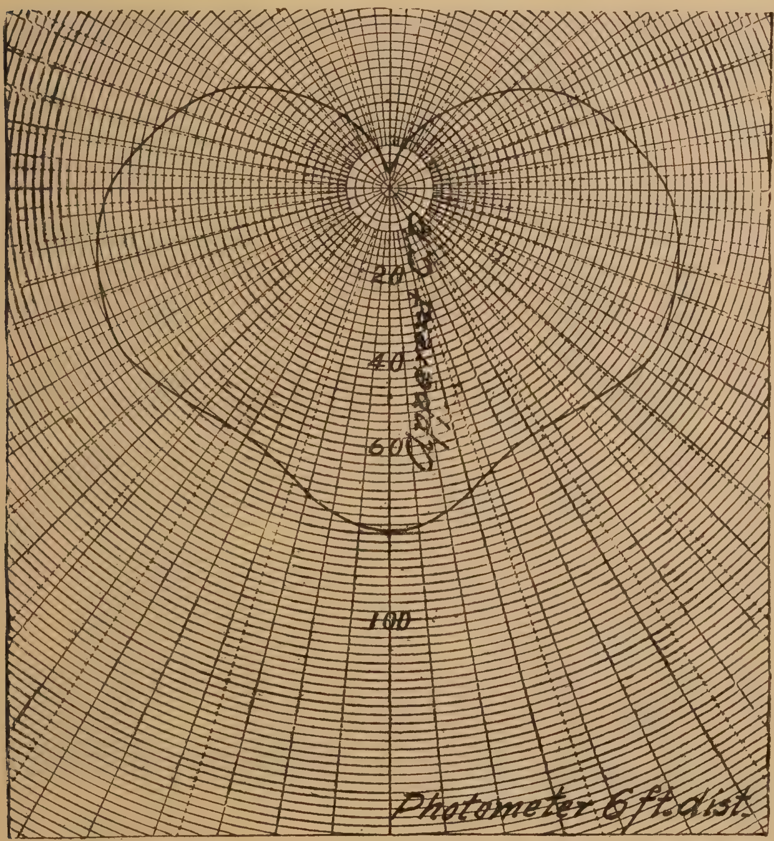

FIG. 26.—Distribution of Light about an Inverted Lamp with Ball Globe.

between outlets. On reference to the plan (Fig. 25) it may be noted that the front and rear outlets were placed in this way, namely, $7\frac{1}{2}$ feet from the front and rear partitions, respectively. With four outlets, two additional lamps would be used to uniformly equip each outlet with a four-light fixture. However, had this pressure of supply been higher than 2 to 3 inches, namely,

4 inches to $4\frac{1}{2}$ inches, the total flux from these lamps would have been increased 20 per cent (see "Per Cent Total Lumens" Curve, Fig. 9), and an intensity of 4 foot-candles could be secured with three lamps per fixture.

Assuming the plane in a shoe store as 1 foot above the floor, the lamps could be placed $8\frac{1}{2}$ feet above the floor. Inasmuch as

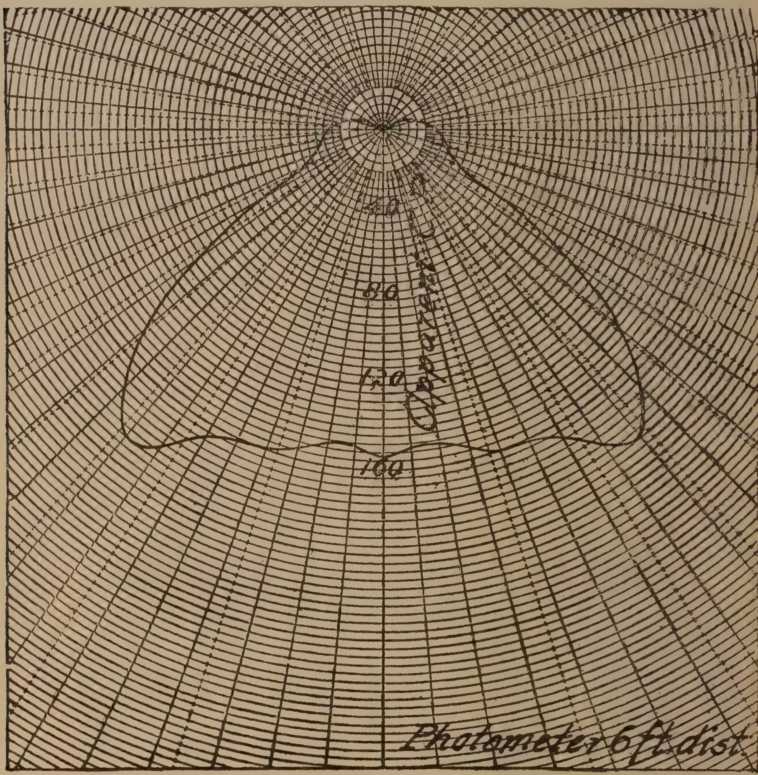

FIG. 27.—Distribution of Light about an Inverted Lamp with Prismatic Reflector.

the ceiling is but 10 feet high in the rear section, it would be better to place these lamps 2 feet from the ceiling, which would bring them 8 feet from the floor; this would result in a satisfactory distribution, as the height to mantle centers above the plane should not exceed half the distance between outlets.

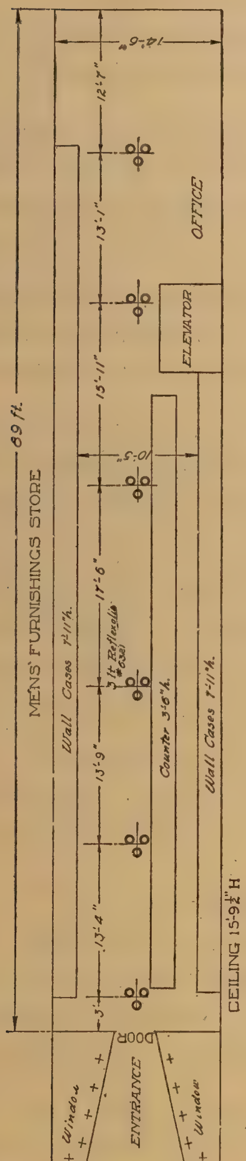

FIG. 28.

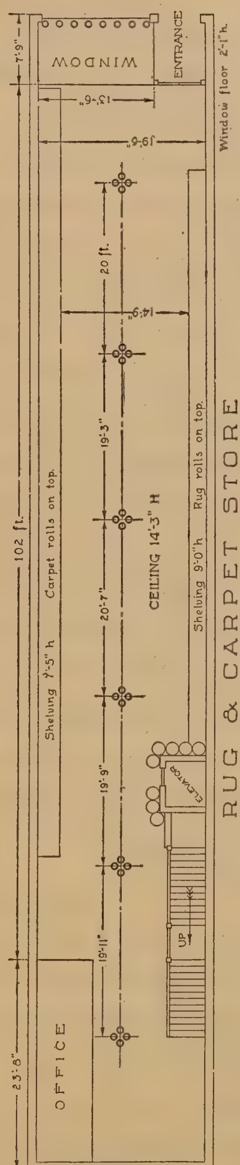

FIG. 29.

FIG. 28.—Plan of Men's Furnishing Store.
FIG. 29.—Plan of Carpet Store.

Analysis of a Furnishing Store Installation

An analysis of existing satisfactory installations will very frequently prove to be valuable examples of the application of this method of calculation.

In Fig. 28 is shown the plan of a men's furnishing store, in a city where rather high intensities of illumination are desired. The ceiling is light, with light walls. This store is 89 feet long by 14 feet 6 inches wide; ceiling height, 15 feet 9 inches. The area, 89 multiplied by 14½ equals 1290 square feet. This area is reduced by deducting for the wall cases to approximately 1007 square feet. Desiring to use inverted lamps with prismatic reflectors (Fig. 27) with the light ceiling and walls, the factor (lumens per cubic foot of gas per hour) is 110.

Therefore, having six three-light fixtures installed, with a nominal consumption of 3.3 cubic feet per lamp, the nominal consumption would be 3.3 times 18, or 59.4 cubic feet of gas per hour. This amount multiplied by the lumens per cubic foot for this equipment, 110, gives as a result 6534 lumens effective, which, divided by the area of 1007 square feet, gives practically 6.5 lumens per square foot, or 6.5 foot-candles. It will be noted that the fixtures here installed are at distances approximately equal to the width of the store, and that the outlets have not been uniformly placed—this is a condition frequently met in practice, where structural conditions necessitate modifications from the ideal arrangement. The changes noted here, however, would insure slightly higher intensities in the front of the store, which would not be undesirable.

Installation in a Carpet Store

In Fig. 29 is shown a plan of a carpet store. The main sales floor is 102 feet long, with a gross width of 19 feet 6 inches, and has a ceiling height of 14 feet 3 inches. Deducting for shelving, elevator and stairway, the area to be considered for illumination would be 1450 square feet. As a high intensity was not desired, practically all the sales being made during daylight hours, the character of service would be classed as "store, medium or dark goods," which in Table No. 5 would demand 4 to 5 foot-candles. The goods displayed on and above the shelving would give the effect of dark walls, that is to say, the reflection from same would be very low. With a light ceiling and dark walls, and an inverted-lamp equipment with prismatic reflectors, the factor is 100.

$$\text{Cubic feet of gas required} = \frac{1450 \times 4}{100} = 58.$$

$$\frac{58}{3.3} = 17.6 \text{ lamps, for 4 foot-candles average intensity.}$$

$$\frac{1450 \times 5}{100} = 72.5 \text{ cubic feet.}$$

$$\frac{72.5}{3.3} = 21.9 \text{ lamps for 5 foot-candles.}$$

Therefore, between 17.6 and 21.9 lamps would be satisfactory for either 4 or 5 foot-candles, respectively.

FOUR LIGHT REFLEXOLIER

No. 6321 Welsbach-Holophane Reflectors—Clear Cylinders.

H	0	1′	2′	3′	4′	5′	6′	7′	8′	9′	10′	12′	14′	16′	18′	20′
4′	36.30	30.78	23.50	17.28	11.50	6.32	3.32	1.75	1.04	.69	.48	.26	.14	.10	.07	.05
5′	23.20	20.90	16.70	13.42	10.30	7.34	4.60	2.73	1.64	1.00	.66	.35	.21	.14	.09	.07
6′	16.10	15.10	12.40	10.50	8.57	6.80	5.12	3.48	2.55	1.47	.96	.46	.27	.17	.12	.08
7′	11.90	11.30	9.61	8.30	7.10	5.92	4.82	3.76	2.71	1.87	1.30	.63	.34	.21	.14	.10
8′	9.06	8.79	7.72	6.68	5.90	5.09	4.33	3.58	2.88	2.19	1.58	.83	.44	.26	.17	.12
9′	7.14	6.98	6.31	5.50	4.92	4.37	3.82	3.29	2.77	2.27	1.79	1.00	.57	.32	.20	.14
10′	5.81	5.67	5.25	4.64	4.18	3.76	3.36	2.96	2.57	2.20	1.84	1.15	.68	.41	.25	.17
11′	4.76	4.72	4.42	3.96	3.58	3.26	2.96	2.65	2.36	2.07	1.79	1.26	.79	.49	.31	.20
12′	4.03	3.98	3.78	3.42	3.11	2.86	2.61	2.38	2.14	1.92	1.70	1.28	.87	.56	.37	.24
13′	3.43	3.39	3.26	2.98	2.73	2.51	2.32	2.13	1.95	1.77	1.60	1.25	.93	.63	42	.28
14′	2.96	2.92	2.83	2.63	2.41	2.22	2.06	1.92	1 77	1.63	1.48	1.20	.94	.68	.47	.33
15′	2.58	2.56	2.48	2.33	2.15	1.99	1.85	1.73	1.61	1.49	1.38	1.14	.93	.72	.51	.36
16′	2.27	2.25	2.19	2.08	1.93	1.79	1.67	1.57	1.47	1.37	1.27	1.08	.89	.72	.55	.40

FIG. 30.—Table of Illumination Values Effective on a Horizontal Plane with the Radiant at Various Heights.

For the area under consideration, five outlets are at present in place, at approximately 20-foot distances. Four-light fixtures, a total of 20 lamps, would therefore appear to be satisfactory. The rear section may be considered separately or a four-light fixture may be installed to maintain a uniformity of fixtures. As the "plane of illumination" in a carpet house is on the floor, counters not being used, these lamps should be at a height of approximately three-fifths the distance between outlets, $20 \times 0.6 = 12$ feet. To verify this height by a "point to point" calculation, the table in Fig. 30 is given.

Horizontal Illumination Calculation

The calculated horizontal illumination results here shown from the light-distribution curve of a four-light fixture may be used in the same manner for a "point to point" calculation, as the data sheet illustrated in Fig. 18. Referring to the 12-foot "H"

or height line in this table, the intensity at 0 distance or directly below the light center is given as 4.03, to which should be added the illumination effective from the two outlets, toward the front and rear of the one considered, each 20 feet distant, of 0.24. Therefore, $4.03+0.24+0.24=4.51$ foot-candles, the illumination on the horizontal plane at the point directly below No. 2 outlet. Midway between outlets No. 1 and No. 2, or No. 2 and No. 3, we would have the sum of the values from each of the two outlets at 10 feet distant, which is given as 1.70. Therefore, $1.70+1.70=3.4$ foot-candles. This is a variation of less than 30 per cent, and in view of the minimum being above 1 foot-candle would not be an observable amount, and would come under the specification for uniform illumination. Should these heights be considered at 10 feet, then the intensities according to the table would be 6.15 foot-candles and 3.68 foot-candles, respectively; a variation of 40 per cent as against 25 per cent at the 12-foot height.

Intensities on any horizontal plane at any height and distance may be determined in the same manner as above, bearing in mind only that the "height" refers to the perpendicular distance in feet, from the horizontal plane chosen, to the center of mantles, and "distance" is the shortest horizontal distance in feet from a point below the source to the point taken on the plane. Desiring the illumination on a table 2 feet 6 inches high placed on this floor 6 feet distant from one outlet and 14 feet from another, the height would be 12 feet less 2 feet 6 inches, or 9 feet 6 inches. The heights given in the table (Fig. 30) are for 9 and 10 feet, and an average will give a reasonable approximation. At 6 feet distance the intensity therefore would be

$$\frac{3.36+3.82}{2}=3.59, \text{ and at 14 feet, } \frac{.68+.57}{2}=.63.$$

Therefore, $3.59+0.63=4.22$, or 4.2 foot-candles (horizontal illumination) effective on the table.

Normal Illumination Calculation

The normal illumination, that illumination effective on any surface at right angles to the ray, may be determined by dividing the candle-power as read from the distribution curve, at the angle effective for the point assumed, by the distance in feet squared or by the sum of the "height" squared and distance squared in feet. Desiring the normal illumination at a point 8 feet below an in-

verted arc lamp and 8 feet distant, the angle would be 45°, the candle-power 528 (see the largest curve, Fig. 13), and $8^2+8^2 = 8\times8+8\times8=128$.

$$\frac{528}{128}=4.1 \text{ foot-candles (normal illumination).}$$

Effect of Height on Distribution

The height at which lamps are hung has a considerable bearing on the uniformity of illumination. If the maximum distribution of light from a number of lamps and reflectors used in large rooms is within 45° to 60° from the vertical, which is true for all inverted gas lamps with distributing reflectors, the height affects the uniformity only. If the light is all directed towards the plane, any height above that at which uniformity is secured, merely results in increasing the areas covered per outlet. These areas effective per outlet will at certain heights be found to overlap. The greater the height, the more will this overlapping tend to uniformity and the softening of shadows without any appreciable difference in intensity. This condition is of particular advantage in large rooms with high ceilings where proportionately large units may be suspended at heights which will admit of a more symmetrical arrangement than would be possible with outlets 15 feet apart, and lamps 7 feet above the floor.

Distribution from Inverted Lamps

In large, high rooms, where single inverted-mantle lamps, equipped with reflectors, are used, the effect on the general illumination values with a light ceiling as compared to a dark ceiling is very slight. It may be noted from Fig. 27 that the light flux in the upper hemisphere is but 10 per cent of the total, and as a consequence the question of how much of the light flux will finally reach the useful plane from a white or light-tinted ceiling is quantitatively so small as to be of little consideration. The curves (Figs. 9 and 11) from bare lamps show a natural light-flux distribution in the favorable proportion of 70 per cent in the lower hemisphere and 30 per cent in the upper hemisphere. The proportionate losses with reflectors is as a consequence invariably less with these lamps than with upright lamps or incandescent electric lamps, having an approximately equal light-flux distribution in each hemisphere.

Show Windows

Undoubtedly, there has been considerable guess-work and ill-directed experiment in show window illumination.

Architects and builders have apparently given very little consideration to this important question. The space in the window at the disposal of the window-lighting specialist is frequently a matter of a few inches.

We have only to observe the show windows in our home city to realize that this very important problem of illumination has been given very little consideration. Windows high or low, shallow or deep, are frequently given the same treatment. Windows containing dark goods adjoining displays of light goods are given the same quantity of light. Little attention has been given to the amount of reflection from materials or fabrics, or to the quality or quantity of either goods or light. Windows finished in light wood or decorations may have been properly and sufficiently illuminated, but when the style of the decoration changes to mahogany or dark oak, the illumination falls off so much that the man who designed the window lighting or the company supplying the gas or electricity comes in for severe condemnation on the grounds of depreciation in the accessories, or gross carelessness in permitting the pressure of the supply to drop off.

Seldom has the fact been made plain that because of the darker finishes a corresponding increase in intensities or change in distribution of light flux is necessary.

The problem of window lighting has two sides, the physical and the physiological. The window may have the right kind of lamps, the correct amount or quantity of light, but because of the physiological effect be condemned. Many installations waste light with arc lamps on the outside, in outline effects, by studded ceilings and other methods, which, if the energy was properly used, would be sufficient to do the work more effectively.

Proper Placing of Lamps for Show Windows

In Fig. 31 is shown an installation where it was desired to illuminate two small show windows with a single outdoor lamp, using five inverted mantles, the lamp being installed between the two windows and about 2 feet out from the building line. It was afterwards shown by illuminometer measurements taken on a horizontal plane near the front of the window, and on other planes

noted in the diagram normal to the eye of the observer on the street, that the illumination from the outside lamp was but half the intensity of that from a single small lamp placed in each

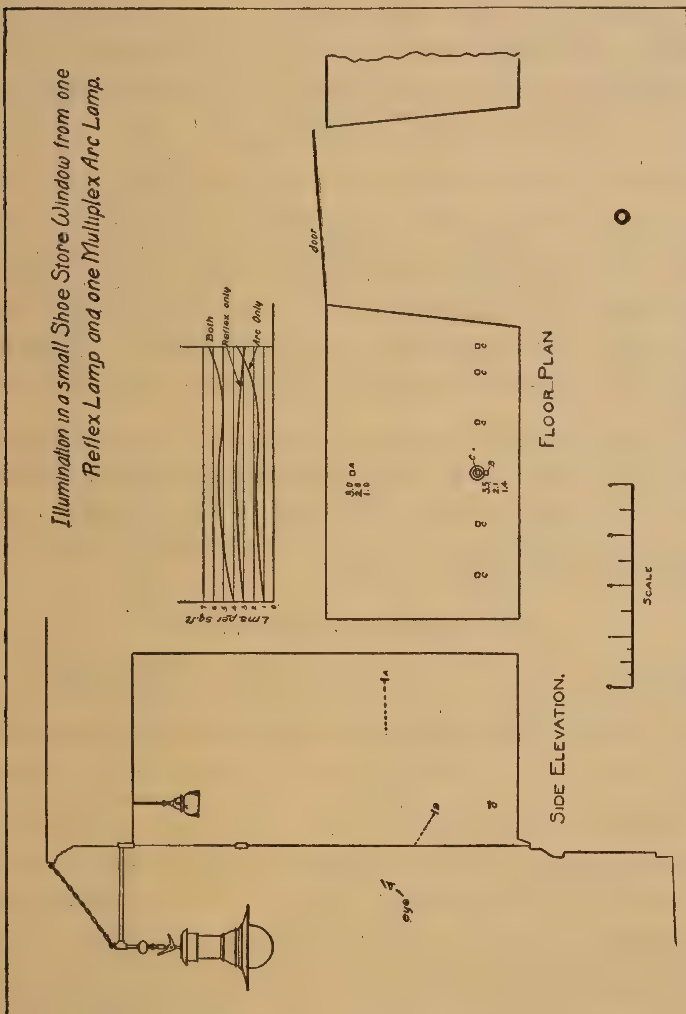

FIG. 31.—Plan and Elevation of Shoe Store Window.

window, the latter having a total consumption of but two-fifths of the multiple mantle lamp. These outdoor lamps are very desirable for brightening up the sidewalk and store front, but are very inefficient indeed for show-window illumination.

The illumination of store windows can, with very few exceptions, be most effectively taken care of with lamps arranged along the front of the window. The lamps should be placed high and out of the direct line of vision. In some cases it is necessary to use a painted band with a sign transparency to hide the lamps; in others, an ordinary curtain or shade will accomplish the purpose, or, where a more simple, dignified treatment is required, a wooden or metal moulding of sufficient depth may be fitted in across the window near the top. The lamps should be equipped with reflectors, which will direct the light downward and back into the window; this will insure the proper direction of light and natural shadows. Shadows are necessary, but should not be sharply defined. We should have no difficulty in distinguishing objects in the shadow, nor confusing the edge of an object with the edge of a shadow. This condition is quite noticeable in a window lighted with a single high-powered unit hung in the center of the window.

A window lighted from the rear and below, with the shadows upward and forward, would be little more unsatisfactory than the so-called shadowless window. All sense of size, proportion, distance and texture are lost or are so badly distorted as to repel observers rather than to attract them.

Light Distribution Calculation

In high, shallow windows, concentrating reflectors should be used; while in deep windows these reflectors would not be satisfactory. A very simple method for determining the distribution characteristics of the reflector to use is shown on the diagram (Fig. 32). This requires a drawing to scale of a sectional elevation, showing the height and depth of the window and assuming a lamp position and plane of illumination. Radial lines (A to F) are then drawn from the mantle center to the illumination plane. The length of these lines squared will then be a measure of the proportionate intensities required for uniform distribution of light on the plane assumed. If $\frac{1}{8}$ of an inch scale were used, and the line A measured 5 inches, the value of same would be 40, and 40^2 (40×40) would give 1600, the value sought, and so on with B, C, D, E and F. In the ordinary window a higher intensity is usual in the front for the better discernment of detail of the objects placed close to the observer. The value secured for A may

then be increased two or three times, while the values at E and F may be halved.

In the above problem of a window in which large objects were to be displayed, a uniform intensity would be satisfactory. The values determined upon for the lines A to F are then plotted to any convenient scale of a lesser value which will bring them up as shown by the curve K. This curve can then be compared with the distri-

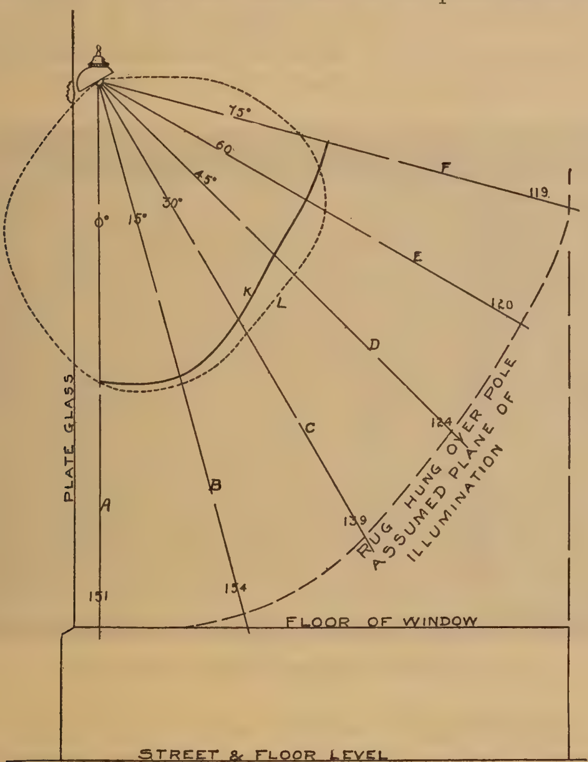

FIG. 32.—Diagram for Calculation in Show Window.

bution curves of the reflectors available, and the one showing the best agreement chosen. The dotted curve L shows a light distribution similar to that shown in Fig. 20.

To Determine the Number of Lamps to Use

It then remains to determine the number of lamps and to place them across the front of the window. The most practical method of determining this number is through the use of "experience

factors," that is, the cubic feet of gas per square foot of show-window floor area. These "experience factors" vary from ⅛ of a cubic foot of gas per square foot of floor area to about 0.6 of a cubic foot, depending upon the local standards of window lighting, the class of goods to be displayed and the ideas of the consumer as regards costs for installation and maintenance.

The carpet-store window shown on the plan in Fig. 29 can be properly taken care of with approximately ¼ of a cubic foot of gas per hour per square foot. The area, 104 square feet, multiplied by 0.25 (¼) gives 26 cubic feet of gas per hour. This, divided

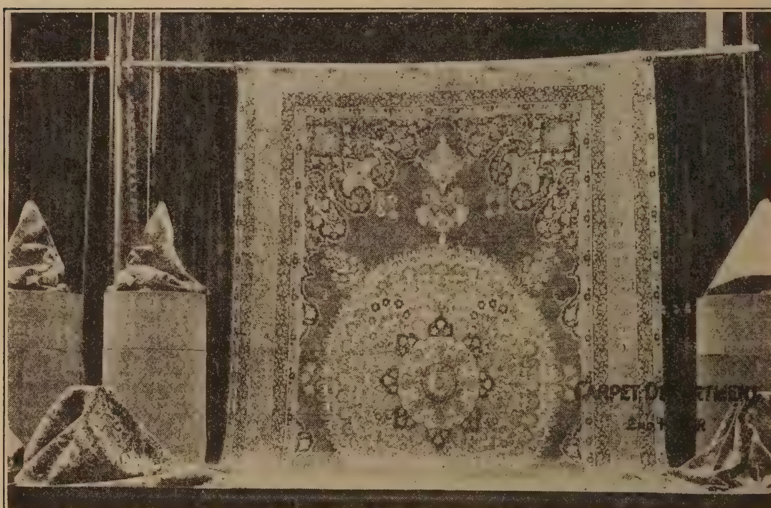

FIG. 33.—Show Window—Night Photograph.

by the consumption per inverted lamp, 3.3 cubic feet, gives eight lamps. These can then be spaced either at equal distances $\left(\frac{13.5 \text{ feet}}{8} = 1.8 \text{ feet or } 21 \text{ inches}\right)$ or not, as desired. An important point is to provide for ample illumination at the ends or sides; the center will be well taken care of by contributions from practically all of the lamps in the row. In spacing lamps, therefore, it should be borne in mind that if ample provision is made for the ends, the center will be well taken care of. In Fig. 33 is shown a window illuminated with a single row of lamps in the front of the window, each lamp being equipped with an angle reflector.

Consideration of Surface Brightness

Working from the theoretical point of view, with the knowledge that the eye is working at a normal pupillary aperture and condition when 1 to 2 foot-candles are effective on the eye, reflected from the object viewed, the object (the goods in the window) may be considered as a secondary light source. Therefore, goods reflecting 80 per cent of the illumination received should be allowed about 2½ foot-candles effective.

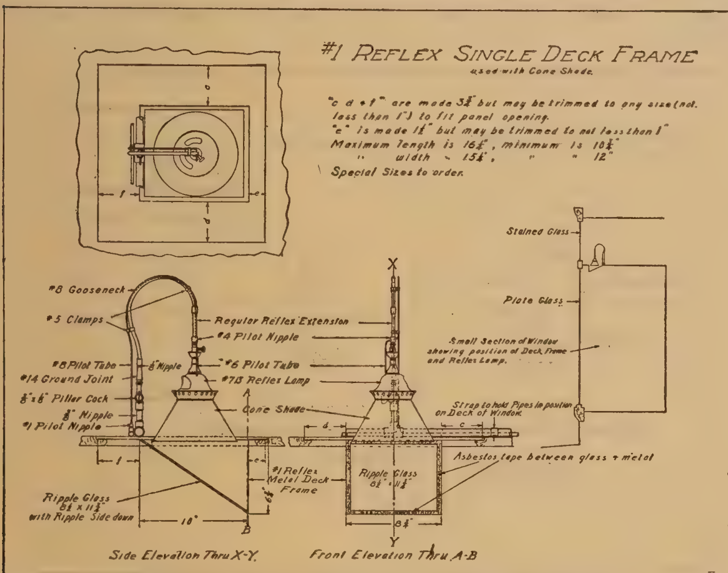

FIG. 34.—Deck Fittings for Cone Reflectors.

Dark goods, from which the reflected light may range from 5 to 1 per cent of the total amount effective on the goods, would require from 40 to 100 foot-candles for satisfactory eye conditions; that is, to see clearly without strain or fatigue, having 1 to 2 foot-candles effective at the eye. The simplest method to determine this quantity would be, of course, by measurement, and with slight changes and a special calibration the illuminometers at present on the market may be arranged for "surface-brightness" measurements. These measurements may be expressed either in terms of candle-power per square inch or per square centimeter, or in terms of illumination in foot-candles, which a white surface would have

to receive in order to have equivalent brightness. This method is also convenient in giving a rough idea of the reflecting powers of the goods displayed in the window. It is merely necessary to use a white disc, the calibration of which is known, and take first a reading of this white disc and then of the surface brightness of the adjacent material. The position of the instrument when these readings are taken should, of course, be on the sidewalk with the instrument at the height of the average observer's eye, and pointed toward those parts of the windows which it is desired to illuminate in such a manner that clear observation of the goods is rendered possible.

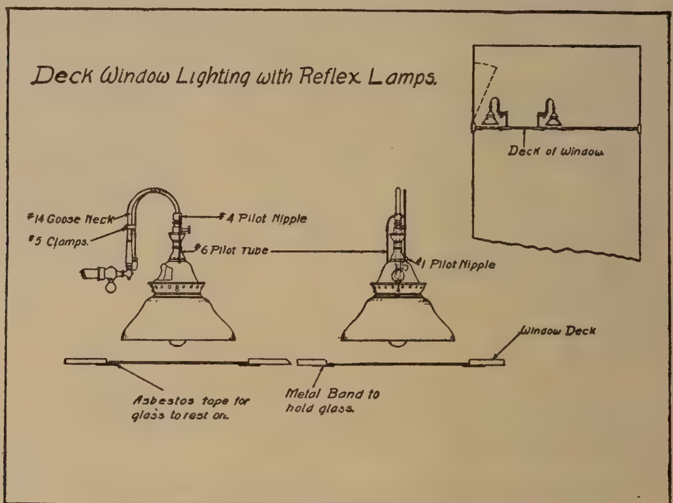

FIG. 35.—Arrangement for Glass Panel.

Deck Windows

The most successfully gas lighted show windows are the installations where the windows have been closed in, commonly known as deck windows. As most gas companies, paying attention to illumination, render a maintenance service, it is much more convenient to have lamps accessibly placed above the deck, that same may be readily examined, adjusted or cleaned, if necessary, at any time without in any way interfering with the goods displayed in the window.

The three Figs. 34, 35 and 36 show successful methods of deck lighting. Fig. 34 is well adapted to narrow windows or windows

where a much higher intensity is required in the front of the window. The deck frames here shown are made of metal, the front section of which extends down into the window slightly more than 6 inches, successfully screening the lamp from the view of those on the sidewalk. Fig. 35 shows a slightly different method, used frequently where goods are dressed flat on the floor of a window, and the direction of the light from the front and the maintenance of shadows is not so necessary or important.

In Fig. 36 is shown a deck fitting similar to that used in Fig. 34, but in this case equipped with an angle reflector directing the

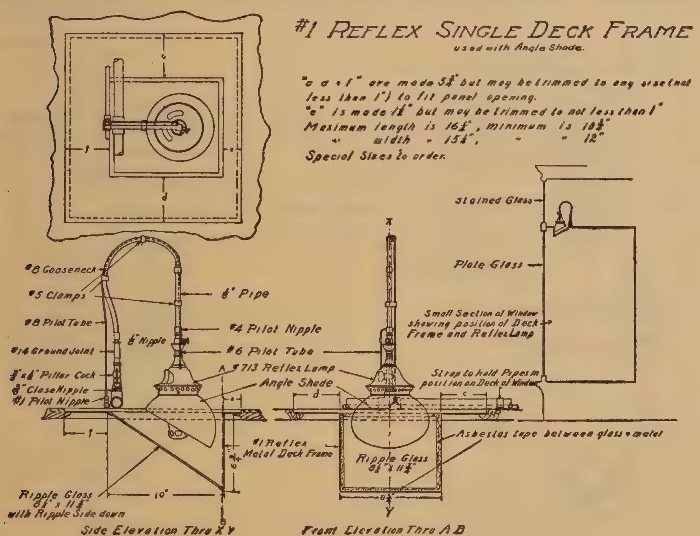

FIG. 36.—Deck Fittings with Angle Reflectors.

maximum light flux at about a 30° angle from the vertical, which distribution is desirable to properly illuminate deep windows.

In many windows a combination of the plans in Figs. 34 and 36 may be used, alternating the reflectors or using a greater or less proportion of cone or angle reflectors. The glass used in these deck frames is commercially known as "ripple" glass, and is a clear glass having an absorption of about 6 per cent. As the ground or sand-blasted glass, which has been used considerably in the past, has an absorption of some 20 to 30 per cent, and presents no advantages over the ripple glass, there would seem to be little justification for its continued use.

In addition to the higher absorption losses with the ground glass, there is also a strong objection to it because of the selective color absorption which results in a predominant green tone to the light; this is quite noticeable even with lamps having as much orange and red rays as the tantalum incandescent lamp.

From illuminometer measurements on an installation, which had been made some time previously, and which was therefore under regular maintenance conditions, in a show window approximately 7 feet high and 6 feet deep, the effective lumens on the floor of a window fitted with these deck frames and alternate lamps equipped with mirror cone-concentrating reflectors and opal angle reflectors,

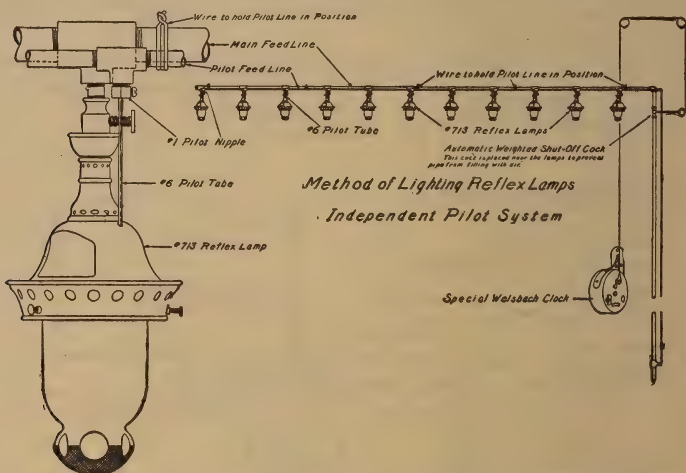

FIG. 37.—Independent Pilot System for Ignition.

it was found that the mirror cone combination delivered approximately 55 lumens on the floor plane per cubic foot of gas, and the opal angle reflectors 34 lumens per cubic foot of gas.

Lamp Ignition for Show Window

In Figs. 37 and 38 are illustrated two methods of ignition for window-lighting installations. Fig. 37 is the independent pilot system, where a small pilot flame is used in the upper part of the lamp at a point where it will insure the certain ignition of the gas issuing from the mantle. The main supply to the lamps is controlled by a time-clock, which may be set to shut off the gas at any desired time. In Fig. 38 is illustrated an electric jump-spark

system of ignition, which has been very successfully used where the installation has been properly made. Considerable difficulty, however, has been experienced in installations where the insulation was not properly taken care of.

Special Problems

In Fig. 39 is shown a very pleasing example of special lighting. This fruit-product display is on the side wall, about midway to the rear, of a large room, the general illumination of which is of very low intensity, almost a moonlight effect, with decorations designed to give an orchard-like appearance to the room. With the high

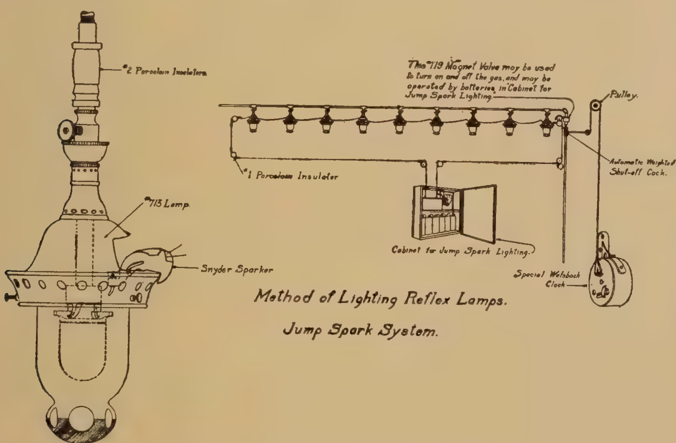

FIG. 38.—Jump Spark Ignition.

intensity on this display case approximately 20 foot-candles, and a low specific intensity on that side of the source toward the observer, this orchard-like setting with the moonlight general illumination effect as a background, results in a novel and beautiful picture.

In Fig. 40 is a sectional elevation of the stand, showing the graphical method of determining the position of the light source and its required distribution. This stand is approximately 7 feet high and 3 feet 6 inches deep at the base; the width is 5 feet 5 inches, and the inclination of the front is at an angle of 26° from the vertical. Assuming a lamp position of 8 feet from the floor and 6 feet distant from the top of the stand, radial lines are drawn from the center of the light source to the plane of illumination at

5° and 10° angles, as described previously for window-illumination problems. The square of the lengths of the radial lines, measured with any convenient scale, preferably one having decimal divisions, will supply the values from which the distribution may be deter-

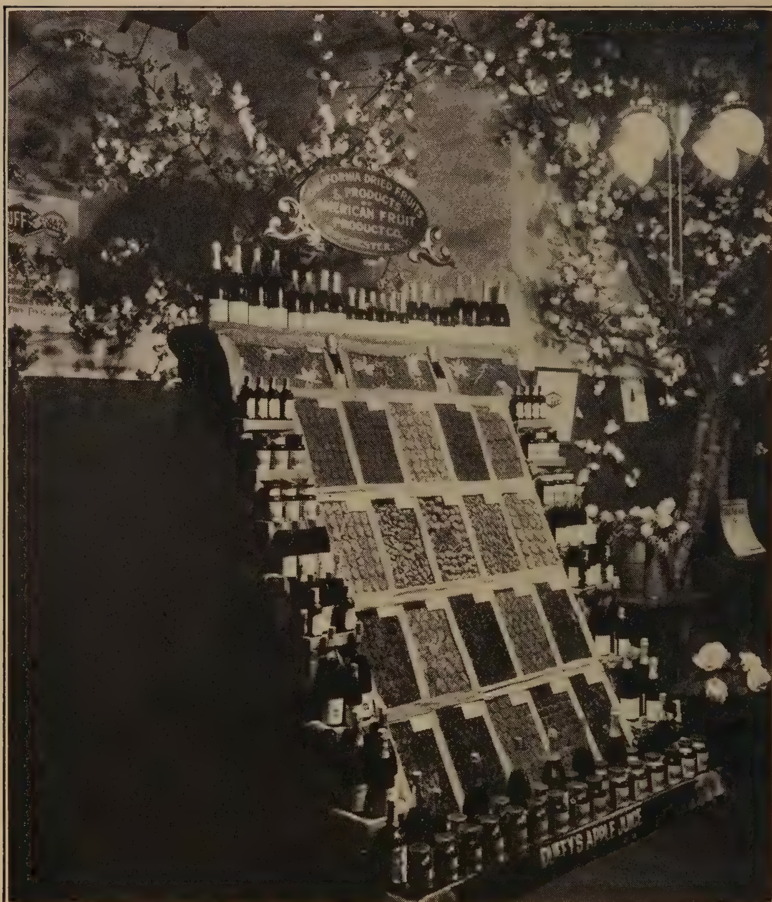

FIG. 39.—Illuminated Display Stand.

mined. The highest intensity was desired at the height of the observer's eye, 5 feet from the floor, the 50° and 60° angle of the source. Taking this value as unity, the other values were reduced by steps to three-quarters on the bottom of the stand. A specification curve was then drawn and compared with available distribu-

tion curves, which resulted in the choice of the unit to be used. The assumed height and distance of the source proving acceptable, it remains to determine the number of lamps required. The area to be considered (5 feet 5 inches by 8 feet), 44 square feet, and

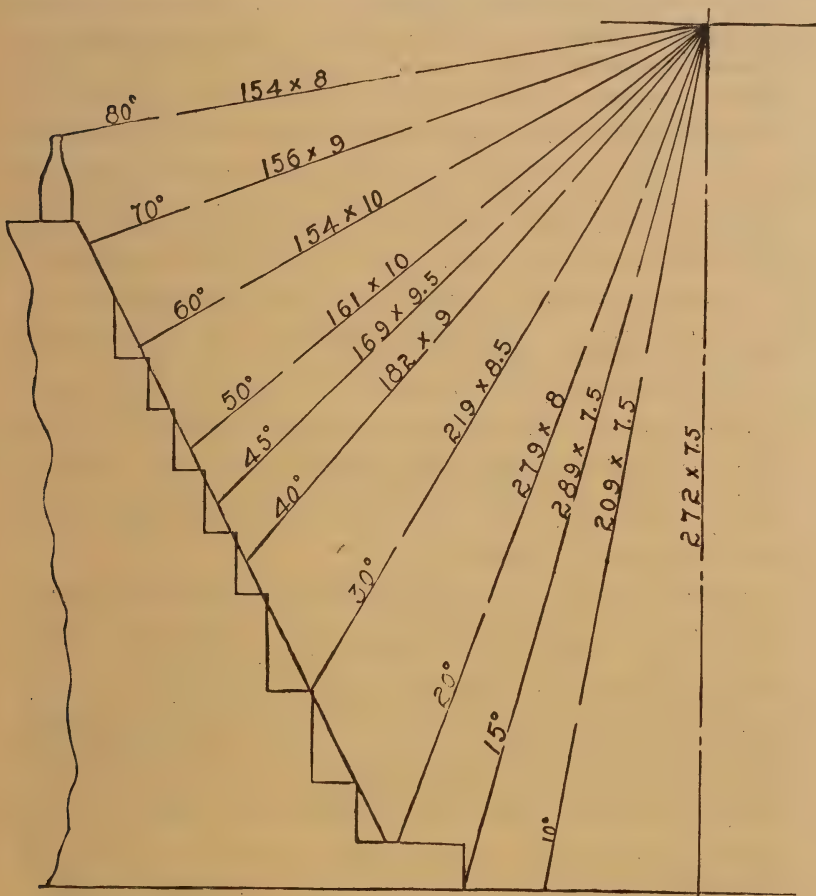

FIG. 40.—Diagram of Display Stand.

assuming 0.3 cubic foot of gas per square foot, allowing for distribution losses based on a circumscribed circle enclosing the rectangular area to be illuminated, gives 13.2 cubic feet, approximately four lamps having a consumption of 3.3 cubic feet per hour.

Residence Illumination

Home illumination, in consideration of the effects to be obtained, is less of an engineering problem, depending as it does on a well-developed sense of the artistic and a knowledge of the various periods of the architecture necessary in the designing of harmonious and appropriate lighting fixtures. Many problems are presented requiring special study to properly secure the desired results. The neglect by the fixture designer to fully consider the various kinds and sizes of lamps and their effect in the production of light, and the comparatively little attention paid up to this time by the engineer to the artistic side of this subject, would seem to leave this field open to those who will specialize in this work; either the engineer may study design or the designer accumulate the necessary engineering data. Residence illumination is not, therefore, merely an engineering problem, as the production of artistic and aesthetic results must always be borne in mind.

A knowledge of the various periods in design is absolutely necessary and must be rigorously followed unless the architect or designer has rendered a modernized conception, in which event the lighting fixtures may deviate from the accepted design in so far that the result may in no way seriously offend the sense of the harmonious and the aesthetic.

Outside of the effect due to the intensity of illumination, there is another element to be considered, which is frequently a factor of considerable importance in modifying one's judgment of the lighting of rooms. The numerous lamps on a chandelier will result in impressions that could not be secured with a single lamp, which might generate the same total light flux. This effect of illumination has no connection with the intensity, but may contribute to an important degree to the final effect obtained. Attention must be given to the subject of color of light and also to the color of surrounding objects, as the character of the illumination is materially affected thereby. The amount of light reflected from surfaces is largely dependent on the color and condition of such surfaces, and is a subject capable of much investigation.

Chandeliers and wall brackets are more often used for their decorative value, and various kinds and sizes of lamps may be used so as to carry out the desired decorative design. The lamps should be equipped with diffusing globes or shades, giving a wide distribution of light.

A Dining-Room Installation

A residence dining-room can probably be more easily and effectively illuminated than any other room in the home; but, notwithstanding the simplicity of the problem, the effectiveness of the installation can be, and in very many instances is, very seriously impaired by using fixtures which are entirely unfitted for the purpose. The opinion has been expressed that careful attention to the lighting of the dining-room will result in more pleasure to the occupants than may be derived from the illumination of any other room in the house.

Various forms of artistic glass domes are popular for dining-room use, and when equipped with a single inverted-mantle lamp

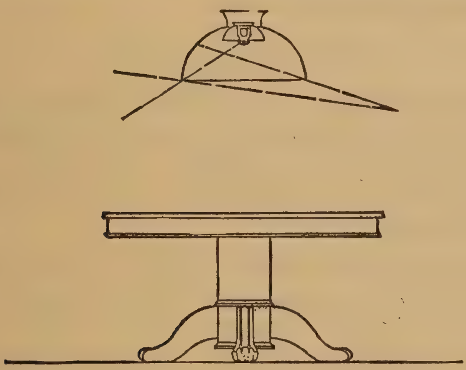

Fig. 41.—Diagram of Dining-room Dome.

will be found to distribute sufficient light flux for the proper illumination of the average size dining-room unless very dark decorations and furnishings are used, in which event additional lamps may be employed either attached to the central fixture or on wall brackets.

The proper height at which to place the dome was made the subject of a thorough investigation, as was also the proper reflector to be used within such a dome. In Fig. 41, on the right hand, is shown the position of the eye of a person seated at the table, when sitting upright, and at the left when leaning somewhat forward. It will be seen that with a dome as here placed, a person at one side of the table can plainly see over the top of the heads of those seated opposite, and at the same time neither the mantle nor the reflector can be seen, unless one leans far forward and purposely

looks up. Placing the dome higher would permit the direct light from the mantle to enter the eyes, while lowering it below the minimum height would cut off the view of those on the opposite side of the table.

The relative positions of the lamp and reflector within the dome should be such that the vertical angle, from the center of the mantle to the lower edge of the dome, is as small as may be secured, thus permitting the location of the dome at the highest point above the table without violating that more important consideration—keeping the lamp out of the direct line of vision; that is to say, having the lamp and all sources of comparatively high specific intensity entirely above the lower edge of the dome when viewed from any position around the table.

Artistic Effects Important

In the proper planning of a well-lighted home in the true conception of effective illumination and a clear understanding of the essential features necessary to produce artistic effects, it is necessary, in selecting fixtures and glassware, that they harmonize generally with the decorations.

In general, it is not advisable to have a uniform illumination.

It is better to use a good general illumination, and where a higher intensity is desired at some particular point to supplement this by some special portable lamp of the desired design and necessary size.

Diffused light is a valuable auxiliary to the effect produced by the direct light. It is diffusion which makes daylight so much superior to all artificial light. The latter illuminates objects in a single direction only, leaving lateral or opposite faces in a shadow, which the light reflected from the ceiling, walls or surrounding objects, may be depended upon to slightly diminish or soften.

In artistic lighting we seek to produce a harmonious blending of lights and shadows, which puts into relief figures, ornaments and decorations, and, as in all other matters where taste is concerned, we should avoid extremes. Economy has no place in this work, particularly in view of the fact that pleasing lighting effects with gas radiants are invariably worth more than their cost.

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XIV (1)

PRINCIPLES AND DESIGN OF EXTERIOR ILLUMINATION

By Louis Bell

CONTENTS

Lecture I

By exterior illumination is meant that which is applied outside the confining walls of buildings. Interior illumination, which is circumscribed by such walls, is powerfully modified by their particular characteristics as to color, texture and coefficient of reflection. Of the six surfaces which bound a typical interior space four or five are generally moderately good reflectors, or at least are not so low in reflectivity as to be at all negligible. One, com-

monly the floor, is often nearly or quite negligible, and sometimes, in the case of high-vaulted ceilings, another bounding surface may be left for the most part out of account. In exterior lighting the case is radically different. In some instances there are no bounding surfaces to the space illuminated of such character or at such distances as to afford any secondary illumination worth mentioning. In other cases there may be two or three reflecting surfaces, generally rather bad, to be considered, but in all cases the upper limiting surface is absent and the condition generally approximates the illumination of an indefinitely extended room with a poorly reflecting floor and an absolutely black ceiling. One, therefore, deals, in exterior lighting, chiefly with light received directly from the radiants, and in so far the case is theoretically simpler than interior lighting. On the other hand, the lower bounding surface in exterior lighting may be relatively important, particularly in certain cases of low illumination to be described later on. Now and then there are lateral bounding surfaces which are not negligible, and there are also extraneous sources of light which in practical illumination are of great importance, but, on the whole, exterior illumination depends for its effective magnitude upon light received directly from the radiants in use.

General Characteristics of Exterior Illumination

From the economic standpoint exterior illumination presents a favorable case, inasmuch as relatively low intensities are employed, since space out-of-doors does not need to be lighted to the degree required for occupations or amusements customarily carried on indoors. Broadly, then, the art of exterior illumination deals generally with the distribution, directly from one or more radiants, of a moderate degree of illumination without much effective aid from any secondary sources of light.

Classes of Exterior Illumination

Most generally, illumination out-of-doors is applied to a single surface, the ground; but there are cases in which the fundamental requirement is the lighting of vertical surfaces, such as are presented by buildings. It is this class of lighting which, perhaps. bears the greatest resemblance to the conditions of interior lighting.

The first class, therefore, of exterior illumination I shall consider

as the lighting of structures, which, for one reason or another, require to be brought into prominence. It is a class of lighting which, to a certain extent, stands by itself in the nature of its requirements, but becomes at times important, and is deserving of especial consideration.

The second class of exterior illumination is that which has to do with the lighting of public places and of parks. It differs materially from the former class in that it is concerned with the distribution of light over the ground surface of a wide area extending in all directions. In the case of public places the lateral bounding surfaces have, to a certain extent, to be considered, while with parks they are generally negligible. In lighting public places the illumination has, both for use and effect, to be carried fairly high, higher generally than in any other class of extended exterior work, and more attention has to be paid than elsewhere to securing uniformity of lighting and pleasing artistic effect. Park lighting, as distinguished from that of other public places, possesses other requirements of usefulness, customarily demands only a moderate illumination, and requires particular criteria of distribution.

Finally, the third class of exterior lighting, and the one of the greatest economic importance, is that of street lighting, in which the distribution has to be chiefly lengthwise of the streets. Bounding surfaces in the form of buildings may or may not be of material importance, and the intensity required is rather moderate. It is lighting in one dimension rather than in two, as in the case of public places and parks, or in three, as in the case of interiors.

Structures

The intent of lighting structures is, for artistic purposes, to bring into prominence at night objects which are intended to be conspicuous by day. It is never a work of necessity, although often desirable as a suitable appreciation of public structures which are in themselves worth seeing. Its laws are, therefore, rather those of aesthetics than those of engineering, albeit the engineering requires peculiar adroitness in order not to defeat the aesthetic end sought. No class of lighting is, upon the whole, worse done, and the few masters of it, like the late Mr. Stieringer, have excelled rather by instinctive genius than by the application of the precedents of engineering.

As to the character of structure lighting it varies very widely, from the mere emphasis of salient details, or strong accentuation of particular objects, to the securing of startling scenic effects by flooding the surface with light or marking it out in lines of fire.

There are, indeed, two distinct classes of structural lighting, one bringing forcefully out, as far as may be, the daylight values of the object; the other, being the evolution, with the structure as a basis, of artistic results in no wise akin to the effects of daylight. An example of the former case is the lighting of a monument, or of the façade of a building, so as to secure the full artistic value of the structure. Into the latter class falls naturally the display lighting of expositions and of special buildings and grounds, *en fête*. In the latter case there is often as a feature the use, too frequently maladroit, of color effects which ordinarily have no part in exterior illumination.

The methods of illuminating structures are as various as the purposes for which the illumination is used. They may include merely the skilful application of ordinary illuminants, the enforcement of their effect by reflectors and search-lights, and the employment of small lights in an infinite variety of ways. The former methods find their largest application in lighting monuments and façades; the latter in the production of scenic effects, in which the more powerful illuminants may be made to play a most useful part. It almost always requires a rather lavish expenditure of energy to secure adequate results unless particular scenic effects only are sought, as in the startlingly beautiful illumination of some of the great towers in New York, where emphasis by night is laid upon single colossal features without any attempt to reproduce the conditions of daylight.

Broadly, one may divide the classes of effects sought in lighting structures into those which have to do with the lighting of surfaces as a whole, those in which particular portions of surfaces are sought to be emphasized, and those which are essentially scenic and decorative in their effects and bring into prominence not surfaces but outlines. Each kind has its legitimate field, but its applicability depends in each case on quite different criteria. In general, the first two classes belong essentially to structures beautiful in themselves, while the last named, if skilfully done, which it generally is not, may lend distinction to things comparatively commonplace.

The superficial lighting of structures, as of the whole façade of a great building, is both difficult to do well and somewhat expensive. Particularly does its apparent expense run high, inasmuch as it is a case of deliberately pouring a flood of light on an exterior generally from a source quite outside the building. The sources of light have a certain detached character that brings their cost sharply into view, while the same expense applied to even inefficient and inartistic grouping of small lights about the structure itself would fail to produce the same psychological effect on the auditing department.

In order to be effective surface lighting must be both somewhat brilliant and very carefully directed. The greatest difficulty in getting a satisfactory result is that due to obtaining the proper direction of illumination. The façade of a building ordinarily is lighted obliquely from above, without sharp shadows, save when the building is in brilliant sunshine. The strength of the illumination falling on a building by daylight may easily run to many hundred or even thousand lux. It is enough, at all events, to bring out a wealth of fine detail even in a very dark building. The coefficient of reflection of a building surface is usually rather small, say from 10 to 25 per cent, at ordinary angles of view, rising notably higher than this, say to between 30 and 40 per cent, only in case of buildings of very light and clean brick or stone, or of very lightly tinted concrete. In most cities the accumulation of dirt due to smoke keeps the reflecting power low. Hence it takes strong lighting, such as is to be had by daylight, to bring the architectural details of the building out at anything like their full value, if these effects are of any delicacy. In the artificial lighting of a façade, the direction of the illumination is necessarily rather from below than from above, and unless the illumination is deliberately planned to provide a dominant direction of lighting the effect is usually to flatten out the projections and sink the detail into insignificance. Light coming indiscriminately from all azimuths along the front is likely to give a disagreeable shadowless effect, and the delicacy of the surface of the structure is quite lost. The illumination should, therefore, be given a predominant direction so as not to lose the effect of light and shade, and, in fact, somewhat to exaggerate it in order to bring out something of the texture in a light dim compared with daylight.

If we could bring ourselves to a really progressive frame of mind, search-lights and reflectors used from points well outside the building to be illuminated could be made to produce much better results than are obtained by any other means, and there is much to be said for so lighting a façade that it shows its architectural value as it is, and not with the addition of freakish lighting effects generally undignified and sometimes ludicrous. Lighting which brings out into prominence some unbeautiful, even though characteristic, feature of a building is as inappropriate as the illumination which I once saw directed against a life-sized portrait of the late President McKinley; it being accidently adjusted so that his nose was the one prominent feature of the display.

A façade with striking features, large and dignified, is comparatively easy to illuminate, while one with a wealth of fine detail requires so much light that the feat of dealing with it adequately is almost impossible. One can hardly imagine, for example, an illumination of the front of the Duomo at Milan brilliant enough to give anything like adequate value to the enormously intricate detail, albeit the Piazza del Duomo is powerfully lighted. Notre Dame, in Paris, on the other hand, with its massive towers and huge flying buttresses, would present a most splendid and imposing appearance under artificial light, even though much detail were lost.

Search-lights and reflectors, as stated above, form the best means of getting adequate surface lighting where large areas are concerned. A slight digression regarding the search-light for this and similar purposes may be here permissible, since the properties of the search-light as an illuminant are generally imperfectly understood. From the standpoint of luminous flux the case of the search-light is a comparatively easy one. From the energy consumed in the arc and the structure of the lamp it is not difficult to form an approximate idea of the lumens which emerge from the system. Then the illumination received on any surface is this total flux divided by the area of the surface in square feet if one wishes to express it in foot-candles, or in square meters if he chooses, as is preferable, the lux as the unit.

The illumination delivered by a search-light system is

$$L = \frac{4\pi e i \eta}{\pi r^2} = \frac{4 e i \eta}{r^2},$$

where e is the voltage at the arc, i the current, and η is the specific

efficiency in mean spherical candle-power per watt × the net reflective coefficient of the mirror system, r being the radius of the incident beam.

Assuming $\eta = 1$

$$\begin{array}{l} e = 80 \text{ v.} \\ i = 50 \text{ amps.} \\ r = 10^m \end{array} \quad L = \frac{4 \times 80 \times 50 \times 1}{100} = 160 \text{ lux.} \qquad (1)$$

Or at the assumed voltage and radius, say 100 lux, would require

$$i = \frac{Lr^2}{4e\eta} = \frac{100 \times 100}{4 \times 80 \times 1} = 31.2 \text{ amps.} \qquad (2)$$

Or, to obtain η,

$$\begin{array}{l} \text{If } L = 100 \\ e = 80 \\ r = 10 \\ i = 40 \end{array} \quad \eta = \frac{Lr^2}{4ei} = \frac{100 \times 100}{4 \times 80 \times 40} = 0.78. \qquad (3)$$

η expresses the specific efficiency of the search-light system as a whole, and should be the subject of systematic experiments.

This rule holds for cases in which the cosine of the semiangular aperture of the beam is near unity, i. e., when the measured illumination is substantially normal; (1) and (2) are subject to a similar limitation. As to the absorption by the atmosphere, it is in clear weather small, amounting, from Sir William Abney's data, to about 15 per cent for the chief luminous rays in transmission through the whole thickness of the atmosphere.

The flux measured in lumens remains the same, barring absorption by the atmosphere, at all distances from the light, and the intensity at the surface illuminated becomes merely a matter of the area of the beam. If it were possible to obtain a strictly parallel beam of luminous flux, barring the small logarithmic decrement from atmospheric absorption, the illumination reached at a surface would be practically independent of its distance and equal to that at the mirror aperture. For a converging beam the illumination increases at all distances up to the focus, while for a diverging beam it obviously diminishes with the distance following the law of inverse squares at all points at a distance large compared with the mirror aperture.

Without the use of lights comparatively distant from the surface to be illuminated, surface lighting becomes increasingly difficult.

It can be carried out to a certain extent with lights on the structure itself, but the effect is not good if more than special portions of the surface are so illuminated. It is an extremely difficult matter to light a surface adequately from a point near itself without either making the light sources too conspicuous or rendering the illumination very uneven. Moreover, lighting at nearly grazing incidence distorts all surface details and destroys their delicacy. It may even produce extremely bizarre and unpleasant effects. Striking examples of the failure of illumination at grazing incidence may be found in the case of attempts to light paintings from reflectors placed near the plane of the canvas, the effect of which is to bring into glaring prominence every brush mark, quite destroying the effect the artist intended to produce.

Only in rare instances can the lighting of a building by sources placed upon it prove effective, and then only when comparatively limited areas are sought to be illuminated, or when the effect intended to be produced is not that of daylight illumination but that of a special form of decoration. Perhaps the most striking success that has been obtained in this line was the lighting of the Metropolitan Life Tower in New York during the Hudson-Fulton Celebration, in which advantage was taken of the structure of the higher parts of the tower so to place the lights upon it as to bring the massive detail high in air into brilliant prominence against the sky. This was in effect a variety of spot lighting which constitutes one of the methods applicable to the illumination of structures.

Spot lighting is, except in such instances as that just mentioned, generally confined to the illumination of monuments or groups of statuary. It too frequently would be better to leave these to the kindly concealment of night, but now and then they are worth the effort at illumination. As a rule, attempts to light such things fail from placing the lights too near, and thereby producing distorted shadows which quite destroy the artistic value sought. Only massive, plain surfaces, such as the Washington Monument in Washington presents, can be adequately lighted from sources placed near the base. Monuments of ordinary types should be illuminated, if at all, from distances several times their height.

Now and then on white surfaces, colored illumination can be used with beautiful effect, as those who saw the Court of Honor at the Chicago Exposition will remember; but these cases are rare

and chiefly confined to temporary exposition work, in which there is small chance for time to destroy the high reflecting power of the surfaces necessary to brilliant effects.

Exposition lighting is an art almost by itself, owing to the immense areas that have to be dealt with and the extreme difficulty of getting suitable locations for lighting buildings upon the outside. The main reliance in such work has in the past usually been outlining by myriads of small incandescents. If skilfully done, that is, done with due reference to the magnitudes and distances of the buildings so as to preserve the *ensemble* effect by night, the result may be extremely beautiful, but if the salient features are wrongly chosen or the ornamentation is exaggerated nothing can, on the whole, return less of artistic value for the energy employed. At its worst, outlining becomes a mere symbolizing of structural lines, as a child might draw them upon a slate. Restraint and keen appreciation of the features of a building worth outlining are necessary to the securing of good results, otherwise the eye will simply be confused by a multitude of lights with nothing to indicate their distance, and will find even individual buildings distorted by the wrong spacing or placing of the lights. On the other hand, when skilfully used, outlining may confer by night singular beauty on structures either commonplace or grimly utilitarian by day. Very striking examples of the decorative use of outlining and similar illuminative devices were shown during the Hudson-Fulton Celebration in New York last year. No one who saw the East River bridges and the stacks of the Water-side station failed to recognize the great artistic value of judiciously strung lights. The bridges from a distance were things of glory instead of grimy skeletons of cable and girder, while the stacks, by day merely solid and purposeful, became beautifully decorated symbolic towers of light.

In attempting to outline buildings it is generally found best to emphasize some of the special features as well as the general contours so that the illumination is not only structural but decorative. In great measure success depends on the judgment of the engineer in fitting the spacing and power of his lights to the particular work in hand. From this point of view it makes a very material difference whether the lighting as a whole is to be viewed from a distance or near by, from practically on a level or from below. As to the proper spacing of lights for general service in such work it

usually runs in practice from 8 inches to 2 feet, while in some instances even these dimensions may be passed. The fundamental thing is to proportion the spacing to the ordinary viewing distance so that the lights will neither run together in a blurred line nor present a scattered appearance. The former limit in the last resort depends on the power of the eye to separate two neighboring luminous points. Many experiments on this sort of visual acuity have been made, and they may be summed up by saying that the eye distinguishes two bright points as separate very easily when they subtend a visual angle of 5 minutes of arc; fairly well when they subtend an angle of 3 minutes; and under favorable circumstances, and with difficulty, when they subtend an angle of 1 minute. These figures are somewhat influenced by the actual darkness of the background, and by the actual intensity of the lights with respect to their production of irradiation. Now an angle of 1 minute is subtended by two points distant from each other by 0.0003 of the viewing distance The 3-minute angle, therefore, corresponds nearly to a separation of one part in a thousand, and the 5-minute angle to one part in six to seven hundred. Around about this latter figure good results are obtainable, and the separation of lamps can often be carried up to 10 minutes of arc with advantage. Closer spacing than 3 minutes is seldom desirable, since only in rare cases does one wish to produce the effect of continuous lines. There is, therefore, a wide range in spacing permissible with which to take account of the important questions relating to perspective.

The effect of the spacing, intensity, and alignment of lights upon nocturnal perspective has played a very small part heretofore in illumination, although it is well understood as a practical art by the masters of stage-craft. Ordinarily, one wishes to preserve the normal conditions of perspective in undertaking artificial illumination. This requirement implies a generally uniform spacing of lights, since the eye instinctively judges the length of a line of bright points by their apparent approximation as they reach the vanishing point. In the case of lines of light generally viewed obliquely the spacing may, however, be widened, since the visual angle between points in such case corresponds to a narrower spacing than when viewed normally. For example, lines of lights festooned lengthwise of a street may be spread far more widely than usual, while still preserving unity of effect, since they are, upon the whole, viewed always from a very oblique angle. Lines of festoons

thrown crosswise of the same street are always seen normally to their length, and consequently should revert to standard spacing.

There are, however, many instances in which lights can be advantageously used not to preserve the perspective but to force it and to create illusions of distance. If one were so placed as to look down a long street, viewing it from a fixed point and not passing along it, it would be possible to produce extraordinary illusions of perspective by varying the spacing and the intensity of the lights. In the absence of any permanent objects upon which the eye can fall to determine distance it is compelled to judge very largely by the apparent perspective. A row of lights down each side of the street diminishing in spacing or intensity, or both, would infallibly call to the mind the conception of indefinite distance stretching out into the night. If, on the other hand, the spacing were progressively increased and the intensity also increased, each within limits, the effect would be to produce an apparent shortening of the vista. These effects may be very pronounced even where there is no deliberate angular shifting of lines in the field of vision to produce illusions of perspective. Lines converged toward an artificial vanishing point abnormally near are, of course, familiar in stage-craft, and by adjusting the stage setting on a diminishing scale with lines thus converged, it is possible to create in great perfection the illusion of a far-reaching space even on a stage of very modest dimensions.

These effects, emphasized by powerful lighting in the near foreground, diminishing toward the rear, are quite familiar, and are often, in fact, overdone. When properly carried out they are immensely striking in effect. The forcing of perspective in this way and the taking advantage of the characteristics of vision to create illusions of direction and distance have been known at least since the time of the builders of the great monuments of Greece. Not only did these masters swell their columns slightly to overcome the illusion of outline presented to the eye at a relatively near view-point, but they even drew the columns together and toward the structure slightly at the top, as in the Parthenon, by an amount not large enough to be conspicuous, yet sufficient to accentuate the height. They knew well, too, how to proportion the scale of their ornamentation to the view-point, and seemed by a fine instinct to have discovered much that in practice has been too often forgotten in the centuries that have intervened. Now this same sort of

effect can be produced by judicious modification of the external lighting of structures. For example, I have had occasion to overcome the tendency of a building, somewhat too tall for symmetry, to vanish into indefinite height as night came on, by powerfully emphasizing the decorative lighting of the cornice and spacing a horizontal line of lights across the front, disproportionately close compared with those above. The effect, as the lights come on in a dark evening, and the towering top emerges out of distant blackness into its proper position is somewhat striking. By such devices as these one can not only overcome the curious distortions produced by night, but can, if necessary, create a wide variety of illusions on a large scale, less perfect, perhaps, but almost as striking, as those worked out upon the stage.

The effect of the intensity of lights in such work is worth noting. It is a curious fact that the eye carries so very imperfect conceptions of intensity. For outlining work, signs and similar uses, 8-candle-power lamps are practically as good as 16's, and 4's about as effective as either. I have actually changed 8-candle-power lamps for 4's on one line of a sign, leaving the other unchanged, without producing any noticeable difference whatever when the sign was viewed from the ordinary distance of several hundred yards. Any brilliant spot, however small, seems to serve the purpose, and the size of the lamps used is really determined rather by the ability to procure them than by anything else. Recent progress in sign work has tended to smaller and smaller lights with positive gain in the effect produced. In attempting, therefore, to create illusions by changing the size of lights, the change has to be an exaggerated one. The use of colored lights in such cases as we have under consideration has been barely touched upon in practice. It is made immensely effective in signs, and has been used successfully in some exposition work for purely decorative purposes, but color as an element in scenic illusion off the stage has scarcely been tried. It possesses, nevertheless, possibilities which are worth much more intelligent study than has yet been given them.

Place and Park Lighting

The lighting of public places and parks differs from street lighting in that the areas to be illuminated are not narrow strips like a street, but extend in both directions, and in the case of public squares the lighting of the adjacent buildings is a thing not to

be left out of account. The purposes of these kinds of lighting differ very widely. Public squares are illuminated with special reference to the convenience and pleasure of the people who use them, often in great numbers. Such places are frequently dense centers of traffic along the streets that meet upon them, are generally located in the more thickly populated parts of the city, and are often scenes of great activity during at least the earlier hours of the evening. Man has become steadily more and more a nocturnal animal, and it is in these public squares that provision must be made for his habits. Both his protection and his convenience are objects which must be borne in mind when designing the illumination. The police value of lighting has long been recognized, and emphasis was laid on it in an interview the other day by the Chief of Police in Paris, who plead for adequate all-night lighting as an adjunct for the preservation of order. In considering public squares the value of ample light as preventive of crime is very considerable, but perhaps less important than it is in some of the streets. A public square is not a spot generally chosen for "hold-ups" or other extreme crimes of violence. It is, however, a location where the pickpocket and petty thief may ply their vocations, and for full protection against these gentry good illumination is needed.

Fundamentally, the lighting of a public square is for the convenience of the passersby. They not only wish to walk without tripping over obstacles, or drive without plunging into open manholes, but they wish to meet and recognize their friends without bumping into them, to glance at a railway time-table, to read the address on a letter or the number on a house, and, in general, to see as comfortably and get about with as little thought of inconvenience from lack of light as would be the case toward the end of a winter afternoon. In other words, the peculiar requirements of convenience demand that public squares which are largely used should be liberally lighted, as well lighted as the best lighted streets, much better lighted than the ordinary streets. It is consequently necessary that they should be lighted with some approach to uniformity, otherwise there will be dark spots not only unpleasant in effect but inconvenient for the man on the street. From a practical standpoint such requirements can be met thoroughly well in only one way, by the use of a very large flux of light from sources placed high enough to be out of the immediate field of view. This is

akin to the ordinary requirements of interior lighting in that one should be able to see easily and comfortably without brilliant sources of light intruding themselves in the direct line of vision.

The lights ordinarily used for street lighting, if sufficiently numerous to give the requisite volume of illumination in a public square, are certain to interfere with vision by their brilliancy and position near the line of sight. I call to mind three famous places which serve as examples of the bad and good methods of place lighting. One of these is the Place de la Concorde, Paris, lighted with innumerable small units placed on short posts that stand in serried ranks all about the famous spot. The lighting of the pavement is moderately bright, but the effect is distinctly unpleasant and inadequate; petty from the great number of lamps and the obtrusiveness of their supports. The second is Trafalgar Square, London, lighted with arcs to a somewhat higher degree than the Place de la Concorde, but yet missing something of distinguished beauty or notable excellence in the results. It is a fairly well-lighted square, which could be made much better were the lamps placed further out of the field of view and the total volume of illumination considerably increased. Finally, as an example of the very best that has been done in such lighting, I may mention the Potsdamer Platz in Berlin, which is brilliantly and beautifully lighted by two groups of enormously powerful lamps placed more than 20 meters above the ground on columns which are themselves works of art by day as well as by night. The actual illumination on the pavement, while amply brilliant, is probably no higher than is reached in Copley Square, Boston, or in any one of several public places in other American cities. The great beauty of the fixtures is the feature which gives to the lighting of Potsdamer Platz its unique position in the art. It is in striking contrast in this respect with the lighting of most American places.

The design of the illumination in a public square is not a simple matter. First, considering the amount of light required in order to meet the requirements of being able to read notes, time-tables and addresses comfortably, as well as to recognize persons quickly and easily, the illumination must be pushed far beyond that found in most American streets unless almost under the lamps. To meet these requirements the average value of the effective illumination should be not less than 1 lux and the minimum should be at least 0.5 lux. Anything less than this is insufficient for the purposes just mentioned and even more is preferable.

One can form a cursory idea what this intensity means by realizing that full moonlight is in our latitude on a clear night about 0.3 lux, a degree of illumination that reduces visual acuity to about 0.25 or 0.30, as shown by actual experiment in moonlight, and reduces shade perception in a similar degree. Both the loss of acuity and the increase of Fechner's fraction below 1 lux are very rapid and at these low illuminations the eye is peculiarly susceptible to the effect of bright lights within the field.

I have just used the term "effective illumination" advisedly, with full knowledge of the fact that there is some discussion as to what constitutes effective illumination for the purpose of lighting such a space as we are considering. It is unnecessary to remind

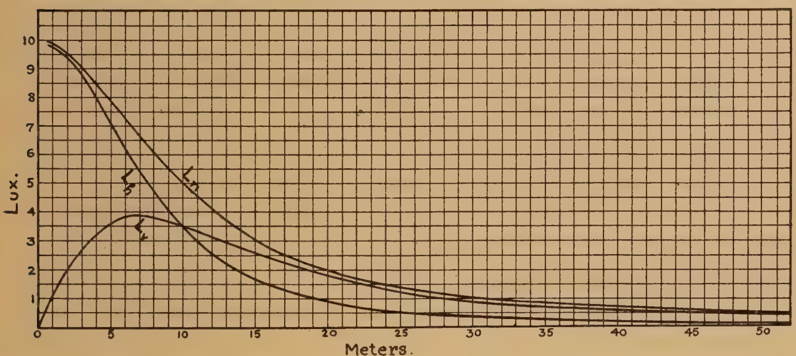


FIG. 1.

you that while the illumination on a surface normal to a ray from a radiant of known power follows simply the inverse square law, if the ray does not fall normally upon the surface the intensity is reduced in proportion to the cosine of the angle of incidence for a horizontal surface, and in proportion to the sine of the same angle for a vertical surface. Consequently, if one attempts to reckon the illumination to be received at a particular point in a public square he finds himself in a quandary as to whether he shall reckon the illumination as on a normal plane, the illumination resolved on a horizontal plane, or resolved on a vertical plane, the three hypotheses leading to three radically different results as to the value of the illumination. The subjoined curves give the three values of the illumination obtained on these three hypotheses from a source of 1000 uniform spherical candle-power placed at a height

of 10 meters. Which of these divergent values should be reckoned as the correct one for the purpose of designing illumination? The question is an intricate one on account of the varying purposes for which one requires light in such a situation.

Here, again, the similarity to interior lighting becomes evident, since the case corresponds quite closely to that of a room lighted from several sources. The solution is, in my judgment, indeterminate, since there are certainly more unknown and perhaps unknowable quantities than definite data which can be applied to them. One can, however, arrive at a common sense approximate solution by establishing this criterion, that the light shall be such as to meet the severest practical test among the various requirements of its use; that is, the reading test. For this one can always readily take advantage of normal illumination, and one customarily does so. This requirement means, therefore, that the normal illumination received from the nearest light shall at no point fall below 0.5 lux, and shall, as a whole, equal or exceed 1 lux. With this quantity of illumination all practical requirements other than reading are met very easily.

The problem of design then resolves itself into a comparatively simple construction, the placing of radiant sources so that if one draws about each of them a circle at such distance that the normal illumination received from the source at that circle shall be 0.5 lux, these circles shall overlap so as to fully cover the area concerned. The subsequent design consists in so planning the distribution from each source that its effective radius of action shall be as great as possible. With all practical illuminants the illumination, if sufficient at the periphery of the circle, will be sufficient for all points within.

For the purpose in hand the fundamental equation connecting the various quantities is

$$L_n = \frac{I}{l^2} \cos^2 \alpha. \tag{1}$$

Where L_n is the illumination, l the height of the radiant above the plane of reference, I the intensity, and α the angle of incidence, which is equal to the angle between the ray and the lamp post. Of these quantities in actual computation any one may be assumed on the conditions, or any one may be required to be found. I and the angle α are dependent variables, and in practice are taken from the distribution curve of the radiant. This being known, the re-

quired height of the lamp to produce a given illumination, L_n can be obtained from the transformed equation,

$$l^2 = \frac{I \cos^2 \alpha}{L_n} \tag{2}$$

For instance, taking L_n at 0.5 lux and I for the angle of incidence 70°, as 2000 candle-power, l comes out at about 22 meters, and it will be generally found that with distributions common for powerful illuminants the heights, for illumination of the order of magnitude here required, come out rather large, higher than it is generally convenient to place the lamps.

Again, the height of the lamp being chosen at some easily practicable figure and the curve being known, the angle of incidence

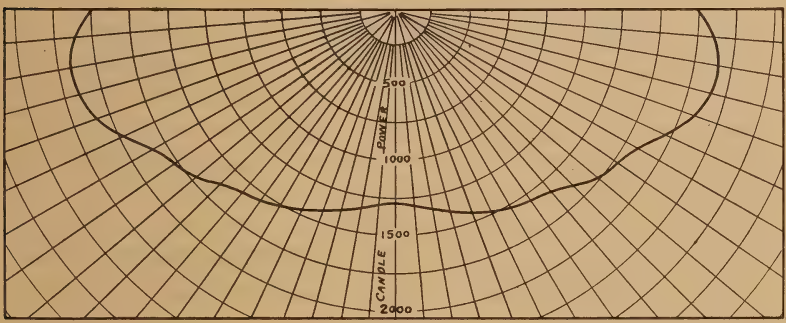


FIG. 2.

corresponding to the required illumination is given by the transformed equation,

$$\cos^2 \alpha = \frac{L_n \, l^2}{I}. \tag{3}$$

Whether the angle of incidence is assumed, or thus reckoned, the radius of the circle for the required illumination at the periphery is

$$r = l \tan \alpha. \tag{4}$$

Since α and I are mutually interdependent, the solutions thus obtained are not exact; but having the distribution curve of the lamp, a slide rule and a table of natural trigonometrical functions, one can get at the facts in the case in very short order. As an example in the application of these formulae the following data derived from the illumination of Copley Square, Boston, which is lighted by four very powerful flaming arcs, may be instructive. Here l equals 16 meters and I is very conservatively taken at 2000 for angles in the vicinity of those dealt with. Fig. 2 shows the curve of the

lamp with opal globe. Applying equations 3 and 4 for L_n equals 1 lux and 0.5 lux, respectively; r equals 41.6 meters for 1 lux and 62.5 meters for 0.5 lux, approximately. Fig. 3 shows these circles of illumination as laid down on a map of the Square. It will be seen that the 1-lux circles overlap liberally, and the 0.5-lux circles almost touch the adjacent lamps. It was considered desirable here, especially on account of the striking adjacent buildings and the large traffic through the streets, to carry the illumination high, and the 0.5-lux circles reach well out into the adjacent streets. The

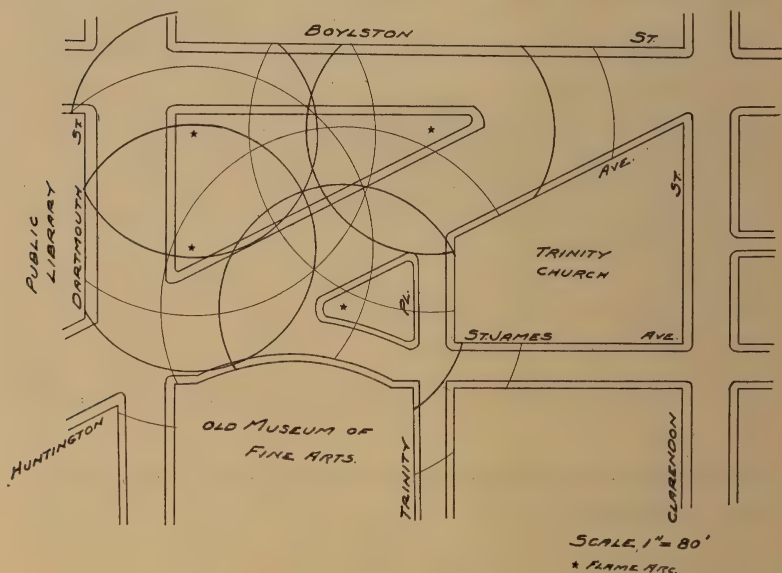


FIG. 3.

great overlap of the circles of illumination renders the lighting extremely uniform, and one can read a newspaper anywhere in the Square without any sensation of glaring brilliancy being perceptible, owing to the great height of the lamps. Ordinarily the 0.5-lux circles in place lighting would overlap about as much as the 1-lux circles do in this instance. Had it been feasible to use poles fully 20 meters in height a slightly different reflector could have been advantageously employed on the lamps with the probable result of increasing the efficiency of the lighting very materially. But the lamps being on series circuits, on which the use of iron poles is not permitted in Massachusetts, it was not practicable to

go higher. Applications of the principle of design here suggested are independent of the power or character of the radiant and will serve for the lighting of public places of any size or importance and to any degree of brilliancy.

Park Lighting

The lighting of parks differs somewhat radically from that of other public places for the simple reason that most parks are so little used after nightfall, except in very limited portions, that any considerable degree of illumination is unnecessary. Now and then one finds a park which is used freely in the evening and in such case lighting on a more liberal scale ought to be supplied, rising, rarely, to that appropriate for other public places. Generally speaking, however, the purpose of park lighting is purely the preservation of order and the marking of what are, so to speak, thoroughfares through the park.

From the police standpoint, which is the important one in park lighting, the requirement is for moderate illumination without dark spots in which the disorderly can lurk. Hence, as a rule, powerful radiants which, unless brilliant illumination is attempted, would be widely spaced and would tend to cause somewhat dense shadows ought always to be avoided in park lighting. Their only proper application in such work is where the illumination should approximate that of other public places and in the case of large open spaces. Parks in general, therefore, require less light than any other class of public spaces which require illumination at all. In many instances where parks are large and wooded there can be no attempt at a general illumination even for police purposes, except in certain spots and along certain routes through the park. Where lighting is attempted at all its intensity along the ways in the park should be the same as in a very moderately lighted street. On such ways it may fall still lower provided it is reasonably uniform, as low, indeed, as average moonlight, perhaps 0.2 lux or thereabouts. The objects to be seen by such lighting being nothing smaller than persons, the demand for visual acuity is small. Practically the problem amounts to furnishing enough light in a certain area to prevent unwarranted persons from lurking in the park after nightfall. Any light, therefore, by which the wandering policeman can make out a figure serves the purpose.

As a result of this police requirement the distribution of lights

in a park has sometimes to be very singular, the lights being placed utterly irrespective of any systematic order, but where they will abolish dark spots under trees and behind shrubbery. For this purpose the lights are preferably of only moderate power and should be placed low where they can shine below the branches of trees. It is also important that lights so placed should be thoroughly screened so as to avoid glare. Under the conditions required the guardians of the peace can fulfil their functions most successfully when their eyes are adapted to a dim light, and dark adaptation is spoiled by a very brief exposure to a powerful light or one of high intrinsic brilliancy. Even incandescent lamps, whether gas or electric, used for such park lighting as is here under consideration should be put in ground glass or opal shades, preferably the latter, so that their light-giving power may be utilized without interfering with the vision of those looking toward them or passing near them.

The best results I have ever obtained in park lighting were with 100-candle-power tungsten lamps in 12-inch diffusing balls, mounted about 10 feet above the ground, and in positions designated after conference with the police authorities. Larger units than these can rarely be utilized to advantage on account of their being too bright, and small ones similarly installed can frequently be made to serve the purpose. If the similar lights are installed along the ways in the park which are desired to be lighted they will do excellent service when so spaced as to give illumination similar to average moonlight, say 0.2 to 0.25 lux. Where people congregate in the park the illumination should be carried higher, up perhaps to 0.5 lux. In open spaces arcs can here be made to do good service, the illumination being planned exactly along the same lines as in the case of the public places already treated. Small units closely placed are less effective except in lighting spaces like open-air restaurants, in which the lights should always be shielded by diffusing balls or shades. The minimum intensity of light in such places should be in the neighborhood of 0.5 lux, enough to enable one to read a menu card or program. Park lighting, therefore, would seem to belong in a special class as regards intensity and distribution, and from its low intensity requires that particular pains should be taken to avoid glare.

The next lecture will take up street lighting, which is at once the most important and difficult branch of exterior illumination.

Lecture II

Street Lighting

Street lighting is in its origin and development essentially a police measure. Its history goes back to mediaeval times, in which the streets, mostly unpaved and wholly undrained, were bad enough by day but worse by night. They were infested by thieves and highwaymen, cut-throats and drunken roisterers with rapiers ready for a quarrel. Paris, in particular, in which we have the first records of street lighting, was the scene of constant brigandage and crime from almost the earliest days of which we have record. Early in the fifteenth century, under Louis XI, flambeaux were ordered at the street corners, and lanterns in the householders' windows to co-operate with the night watch in promoting public safety. Over and over again for the next two centuries and a half such ordinances were reiterated, always openly on the score of public safety from crimes of violence. In 1558 lanterns were ordered, at the corners of streets and at other suitable places, to be kept burning from 10 o'clock in the evening till 4 o'clock in the morning through the winter months. By these dim and flickering lights the course of the streets was at least marked, but they afforded scanty protection against marauders, and those who could afford it went accompanied by a retinue of torch bearers and an armed guard when traversing the streets at night. It was not until more than a century later that anything approaching public lighting was seriously attempted. In 1662 the first public lighting concern was given a franchise under a royal edict of October 14. This was a private enterprise of the Abbé Laudati, and its chief feature was the constitution of a corps of public lantern bearers carrying lanterns or flambeaux of a specified size and bearing as insignia the arms of the city. These were stationed at fixed posts along the streets and for a small fee would escort the nocturnal wanderer more or less safely on his way. The street lighting proper was strengthened at about this period, and the effect on public order seems to have been immediate, for at least two medals were struck within the decade, celebrating the institution of public lighting.

London was still worse off and save for the transitory effect of ordinances requiring householders to hang out lanterns the streets were unlighted and almost as full of danger as those across the

Channel. Pepys, in his immortal Diary, over and over records the darkness and danger of the streets, the highwaymen prowling upon their evil errands, and mentions driving fearfully home at night with a drawn sword lying across his knees in the carriage. It is worth noting that about this period some ignoble soul, whose name has very properly perished in oblivion, devised the original moonlight schedule as a measure of poor and pitiful economy. It was tried first, probably, in Paris, where it was railed against as "candle-end economy." London copied from Paris, and had made little progress before the end of the seventeenth century. At this period, however, the chief streets of Paris were systematically lighted by lanterns swung across the street, still the most efficient position for street lights. They were placed at about 20 paces apart and hung some 20 feet above the ground or pavement, as the case might be. It was well into the eighteenth century before street lighting at public expense was customary even in the capitals of Europe. The subsequent 200 years has seen an immense change in methods and material, but the purpose of street lighting has remained the same, and it is now, as it was 4 centuries since, a measure of public safety and an adjunct to the police force.

For practical purposes the street lighting of the seventeenth and eighteenth centuries was altogether insufficient and ineffective, but despite this it was found, as it is found to-day, a great preventive of crime. As the use of the streets by night has increased the necessity for lighting has grown with it. Lighting to-day bears a closer relation to public safety than it did when the only occupants of the streets after nightfall were a few crawling carriages and a few belated pedestrians. It is necessary not only to light the streets well enough to mark their course and serve for the assistance of the guardians of the peace, but well enough to distinguish the way clearly, to avoid obstacles even when going at fairly high speed, to distinguish and recognize persons and to tell where they are and what they are doing. The police should be able to note the actions of suspicious characters before they stumble over them, or to detect the number of a law-breaking automobile before it has vanished into the distance. All these requirements of a complicated civilization demand lighting upon a vastly more liberal scale than sufficed for earlier days, or than is found in many localities even now. It is pertinent then to inquire into the conditions of visibility that are present with artificial light in the streets,

and to find their bearing upon the intensity of light required.

Except in the vision of details at comparatively short range we see things in virtue of their differences of color and of luminosity. In weak light color as such is inconspicuous, so that practical vision depends chiefly upon the power of distinguishing differences of luminosity. So far as the problems of artificial illumination are concerned objects do not range over a wide scale of luminosity. Whatever may be the absolute values of light received the relative values as expressed by the coefficient of reflection range practically from about 0.8 to 0.04, or a little less. In other words, the blackest object returns about one-twentieth the light returned by the brightest object. Ability to distinguish between stationary objects by their difference in luminosity depends then on the capacity of the eye as regards shade perception. The fundamental fact underlying this is that the eye can perceive within a wide range of absolute intensity a fairly constant fractional difference in luminosity. This is the meaning of Fechner's law, and the fractional difference is that known to physiologists as Fechner's fraction. In bright light it ranges, say from 2 to 0.5 per cent, with modest variations under special circumstances both ways from these values, which hold measurably well for values of the illumination from about 10 lux up. As the illumination falls below this point there is a material increase in Fechner's fraction under ordinary circumstances, and we see less well, so that by the time the illumination is down to 1 lux our shade perception is very seriously impaired, as is also our ability to distinguish details, visual acuity. It should be mentioned in this connection that the loss of shade perception at low illuminations is very powerfully influenced by the state of adaptation of the eye with respect to light or darkness. With the eye well adapted to the dark fairly good shade perception can be carried to illuminations very much lower than ordinary. In fact at 1 lux or a few tenths lux the value of Fechner's fraction is influenced very much more by the state of the eye as regards dark adaptation than by anything else, so that when one is seeing fairly under a very low illumination, anything which tends to spoil the dark adaption produces immediate blinding with respect to things otherwise easily seen. It is chiefly this fact which, from the standpoint of street illumination, renders glaring lights so troublesome.

Referring these things to the physiology of vision the situation

may be summarized by saying that below an illumination of 1 lux normal daylight vision, which is chiefly associated with the cones of the retina, is rapidly failing and throwing the burden of vision upon the rods.

Right here a word regarding this "duplicitäts-theorie" of which Dr. Cobb spoke, which is the root of most modern theories of vision. Hinted at by Abney, Charpentier, and others, it was first clearly formulated by von Kries in 1894. By it the retina furnishes a groundwork of colorless light perception which acts at all intensities, as in peripheral vision. On this is superimposed color vision, the function of the highly variable and irregularly disposed cones, which morphologically are, as Cajal has shown, modified rods. These cones, like color-sensitive photographic plates, are of relatively low sensitiveness, failing to respond well to stimuli below about 1 lux, and ordinarily responding only very feebly below ¼ lux. The rods retain their sensitiveness long after the cones have ceased to respond, especially when in comparative darkness the regeneration and migration of the visual pigment is going on. In full dark adaptation the sensitiveness rises more than a thousandfold, as if the fresh pigmentation acted as a sensitizing bath. The process takes 10 or 15 minutes, although less than half this time will completely destroy the dark adaptation gained, and a few moments will seriously impair it. Adaptation concerns the cones very little under ordinary conditions, although there is some reason to believe that in extremely protracted dark adaptation the pigment migration may reach and sensitize the cones.

Now pure rod vision is poor vision—bad in acuity, bad also in shade perception. Moreover what of acuity and shade perception is left is almost wholly a function of the dark adaptation, which is promptly ruined by exposure to bright light, and regained but slowly. We cannot see details by rod vision alone, and when we want to see details we must push the illumination to the point of active cone-vision. The trouble with street lighting, in general, is that it has dealt chiefly with the last fading traces of cone vision. It is constantly on the very edge of that twilight vision which is scarcely real seeing at all without full dark adaptation. To get results we must go to one side or the other of the line—either provide enough light for daylight vision or, if we trust to twilight vision at all, see to it that the all-important dark adaptation is preserved.

There is, then, a physiological dividing line that can be drawn between illumination which permits fairly good seeing and illumination which leaves only the residual twilight vision, between the illumination which enables one to perceive things with some degree of definiteness and that with which one perceives chiefly forms and shadows. The exact position of this line is somewhat difficult to define as it varies more or less in different eyes and under different conditions. At 0.5 lux one has certainly not passed fully into conditions of twilight vision. Color perception though much impaired has not disappeared, and acuity, though failing, still remains in sufficient degree to permit casual reading, although with some little difficulty.* At 0.1 lux a condition is reached where one depends almost entirely on rod vision. Acuity has been enormously reduced, and shade perception has become almost wholly dependent on dark adaptation. The point at which cone vision goes rapidly out of service, and rod vision as rapidly takes its place for what it is worth, is somewhere about 0.2 or 0.25 lux, and daylight vision is not very dependable below 0.5 lux. We have here then the physiological characters of the eye which are already well determined by investigation directed particularly upon them, as the basis of a physiological criterion of illumination. The nature of this with respect to ordinary working illumination for various purposes I set forth some 3 years ago. The present references simply extend the same theory to the conditions of street illumination. In twilight vision one sees things not as distinctly perceptible, but as dim forms and shades of uncertain boundaries and character. Only when the objects subtend a fairly large visual angle does one see them in the least clearly. This is the familiar vision of a bright starlit night or a dimly illuminated street. In its beginnings one cannot even distinguish large stationary objects from their background. The first perception is that of objects in motion, which seem to catch the eye more readily than when they are at rest. This is a familiar phenomenon in trying to pick up objects with a night glass at sea. They can be caught by sweeping when they quite escape detection on apparently slower and more careful search. This, too, is probably characteristic of the vision of nocturnal animals.

The next stage of vision presents objects either as vaguely sil-

* One can, for instance, still read by the light of a candle 1.4 meters distant.

houetted against a lighter background or as faintly lighted against a darker background. By further increase of lighting some details begin to be perceptible, and when the illumination has passed the critical point of 1 lux or a little more, to which reference has been made, further details spring rapidly into view and objects take on a more natural aspect. The interesting theory of silhouetting as a feature of street illumination, which has been recently advanced, really concerns chiefly twilight vision and emphasizes the desirability under this condition of having a light background, not because one can see a dark patch on a light background any better than a light patch on a dark background, but because many things, and particularly the large things, which alone fall within the scope of twilight vision, are themselves commonly rather dark in surface and, consequently, are not easily rendered lighter than the background. On the other hand, many objects are of surface lighter than, say, an asphalted street, and, consequently, are seen as light objects, while commoner than either condition is that of seeing an object in twilight vision only by its shadow, as one sees a distant pebble in the street in the beam of an automobile searchlight.

No illumination which depends chiefly on twilight vision can be seriously considered for the ordinary purposes of street lighting. It has its useful place in merely enabling one to find the way. To be effective for the purposes of ordinary traffic, or as an adjunct to proper policing of a city, illumination must be sufficient to establish, at least to moderate extent, the conditions of cone vision. The wayfarer wants to distinguish the shadow of a post from a hole in the pavement before he is fairly upon it. The man who is driving along a street needs to see his way clearly without risk of running into the gutter, and the policeman should be able to tell a belated householder from a burglar using his jimmy on a front door. And, finally, in many places it is highly important to have enough additional light to distinguish faces readily, to see even trivial obstacles easily and to read the numbers on houses or, if need be, consult an address book or a time-table. These considerations lead inevitably to the conclusion that unless one is prepared to meet the most exacting conditions of street illumination throughout the city he must be willing to classify the lighting that is to be undertaken, and to light each street according to its needs, bearing in mind the amount and kind of nocturnal traffic,

and particularly the requirements of public order. I shall here consider streets as divided for the purpose of lighting into first, second and third classes.

By first-class streets I mean the chief streets of a city from the standpoint of amount of nocturnal traffic and the requirements of the police. A chief street may be the principal business street of a city, that is humming with activity after nightfall. It may be a street leading to a crowded railway station where carriages and foot passengers are constantly circulating until late in the evening, or it may be a comparatively humble business street in a portion of the city where the police have found from experience that only constant watchfulness can keep down crime. The streets which require first-class illumination are by no means only the streets of stately business blocks or magnificent residences.

The ordinary streets of a city or town fall into another category. Traffic after nightfall is light or only moderate. The streets are reasonably orderly and the general conditions are such that neither from the view-point of the wayfarer nor from that of the policeman is brilliant illumination necessary. Such streets are the ordinary quiet residence streets of the average city and the business streets on which there is little traffic by night. These streets usually would figure up to two-thirds or three-fourths of the total mileage in the average city. These may be regarded as second-class streets from the illuminating standpoint, requiring good lighting, but not of the highest pitch of brilliancy. Finally, there are in every city a number of streets which require practically very little illumination. They are mostly in the outlying portions of the city, sometimes scantily built up, and sometimes they are mere roads leading away from the structural part of the city, but still within its jurisdiction. For such streets it is necessary to provide only such illumination as will serve to mark the way and to render progress through them easy considering the conditions of traffic. Occasional outlying streets, not at all important as residence streets, are still considerable traffic carriers, being through-roads from one part of the city to another, or from the city to some particular suburb or neighboring town. In these days of very great use of motor cars almost everyone will recognize in his own city streets to which this description applies. Such, from the standpoint of the illuminating engineer, are second-class streets rather than third-class streets. They demand the illumination required by

considerable traffic. It is difficult to lay out any exact criteria for this classification, but there is no chief of police who could not, after a little reflection, make it with practical precision.

As to the intensity of lighting required for streets of these several classes the requirements have by popular consent been slowly and steadily rising. On the physiological basis which enables one at least to determine what lighting is necessary for reasonably good vision for various purposes, one can form a fair approximation of conditions to be met. First-class streets in constant use for dense traffic of one kind or another, or so classified from the police standpoint, certainly require reading illumination, and this is the kind of illumination that first-class streets get in most European and some American cities. The intensity of the illumination required is practically that already specified for public places, that is, an extreme minimum of at least 0.5 lux, an average of fully double that amount. Theory and practice concur in holding that a street so lighted is well lighted. The same question arises here as regards the way illumination should be reckoned that was answered concerning the lighting of public places, and the answer is much the same for both cases. In each case it should be understood that the minimum cannot be permitted to apply to any material portion of the street area. The intensity here specified mainly on theoretical grounds is substantially that deemed advisable by several foreign investigators and carried into practice with entirely satisfactory results.

As regards second-class streets the requirements are, of course, less severe. There should be, as a matter of convenience, light enough to recognize a friend without stumbling over him, to read an address, or see the number of a house comfortably. The average illumination for this purpose may be set at not less than 0.5 lux, and the minimum should be high enough not to drive one into the physiologically undesirable condition of relying upon rod vision only. This would imply that the minimum should be nowhere less than about 0.25 lux. Streets so lighted will be comfortably bright near the lamps, and the lighting will be as good as moonlight even at the darkest spot. This degree of illumination is excellently serviceable for the majority of second-class city streets.

Finally, we come to the third-class streets. If there is light enough to mark well the way and see persons or vehicles in ample time to avoid them it is sufficient. The degree of illumination re-

quired need not be greater than is afforded by bright moonlight, and should be as great as one finds in rather dim moonlight. It is illumination similar to that which is required for some of the park lighting, to which reference has been made, ranging, say, from 0.30 down to 0.1 lux, or thereabouts. At such low intensities it would be better to cut down the intrinsic brilliancy of the lights by screening, as in park lighting, so as not to spoil the dark adaptation which is necessary for utilizing so low a degree of light. In streets so dimly lighted the silhouette effect is rather marked, and it is not desirable to forego the advantage of a tolerably light surface on the street. The coefficient of reflection of roadways varies greatly according to their surface and the angle of incidence. At fairly large angles of incidence a dirt road or a dusty bit of ordinary macadam may give coefficients as high as 0.25 to 0.35; under similar conditions a dark pavement or a bit of oiled macadam may give coefficients from half of these figures down to as low as 0.05, which low values greatly increase the difficulty of proper illumination.

Considerations of economy in street lighting enforce such classification of streets as here described. Few cities can afford even at the present scale of public expenditure to light brilliantly any large proportion of their streets. If an attempt were made to light all the streets alike there would be no first-class lighting at all. In small cities where the traffic is never very dense, and the use of the streets at night moderate, very little first-class lighting is required, and the amount necessary will diminish with the traffic. The burden of lighting perhaps falls more heavily on small cities than on large, owing to the large amount of street mileage compared with the assessable values. Hence, in such places, there will be, and properly may be from the conditions, a relatively considerable amount of third-class lighting, but even so the cost of lighting is sometimes a serious matter. To keep down expense and yet to adjust the lighting conditions as well as may be, various attempts have been made to reduce the hours of lighting per year while yet meeting fairly the practical requirements. The earliest attempt of this kind, to which reference has already been made, was based on cutting out all the lights on moonlight nights. This scheme is apparent in the various moonlight schedules which have been used. Such schedules are all unsatisfactory for the reason alleged against them from the beginning that the weather is no

respecter of moonlight, and the nights near full moon are, in point of fact, sometimes as dark as the darkest. The only suitable lighting for cities of any importance is the all night and every night schedule. This is commonly based on starting the lamps half an hour after sunset and extinguishing them half an hour before sunrise every day in the year. This amounts to a total of nearly 4000 hours per year. For any given locality this should obviously be based on local time and not on standard time. The intervals between sunset and lighting, and extinguishment and sunrise are subject to some modification in the practice of various cities, varying practically with the season of the year, but the all-night and every-night schedule will be found to run between 3900 and 4000 hours, seldom being less than the former or exceeding the latter. If the full schedule as first suggested is to be modified at all it is better to modify it in the morning hours than in the hour of lighting up by reason of the greater traffic in the evening.

The so-called moonlight schedules vary considerably according to the tacit assumptions made regarding the effectiveness of moonlight, but run commonly a little over 2000 hours per year. A modified moonlight schedule, as used in a number of cities, starts with lighting from dusk to midnight every night, and takes on the moonlight schedule by extinguishment approximately an hour after moonrise after midnight. Such schedules run to about 3000 hours per year. The reduction in cost is not, of course, proportionate to the reduction in hours, so that the economy is to a certain extent rather apparent than real. A better plan is followed in some European cities of lighting all the lights every night from dusk to midnight or 1 o'clock, and then extinguishing part of them, sometimes every other light. Now and then this scheme is varied by having supplementary incandescent lamps attached to each arc pole and throwing these on during the morning hours. On the whole, this plan is likely to give better illumination than any form of moonlight schedule, but is less easier applicable here than abroad, since here most lights are on series circuits while there the use of multiple connection is almost universal. No really effective scheme for cutting down the hours of lighting while yet adequately lighting the streets through the hours of darkness is reasonably to be expected. The only question that may properly be raised is whether it may not be feasible, say after midnight, on account of the changed conditions in the streets, to regard certain first-

class streets as second-class streets, and hence to reduce the illumination in them by cutting out say every other light, which, in a liberally lighted street, if planned for in advance, is not impracticable. The same reasoning might apply to a few second-class streets. A consistent application of this principle might reduce the average hours of lighting per year from the 4000 of the all-night schedule to some point between 3000 and 3500 hours, depending on the number of lights affected. If rigorous economy in street lighting is absolutely necessary the line suggested is the logical one to follow.

Before passing to the practical design of street lighting it is worth noting that while I have here reckoned the illumination as for normal incidence it is the usual practice abroad to reckon the horizontal component. This, as has already been seen, makes a very great difference in reckoning back from the required minimum illumination to the necessary power of the radiant. On the other hand, when reckoning the horizontal component one is at liberty to sum up the light received from both directions on a street or from all directions in an open space. I prefer, myself, to consider only normal incidence and lights from one direction only, since it is this condition which must be considered in those uses of street lights which require the strongest illumination. If the lighting meets the severest requirement it will also meet all the others. Objects of which the details are to be made out are generally held so as to be lighted from only one direction, and hence it is this which must be considered. In point of fact the European practice is perfectly sound as regards the results, because with a minimum requirement set quite as high as I have indicated there is no doubt about getting sufficient normal illumination when the horizontal requirements are fulfilled. Furthermore, with the radiants commonly employed for street lighting and spaced so as to get the required horizontal component, the height of the radiants above the street is such as to approximately fulfill also the requirement for normal illumination. For instance, the common spacing for arc lights in Continental cities is for chief streets about 30 to 40 meters, and the lamps themselves being commonly hung 8 or 10 meters high, the angle of incidence rises to the vicinity of 30°, and hence it is numerically a matter of indifference whether one reckons the light received at this incidence normally from a single lamp or the horizontal component from a lamp on each

side. Thus, in effect, the two methods of measurements lead to practically the same result when the lighting fulfills the necessary requirement for intensity on either theory of procedure. The plane of illumination, that at which the required intensity should be found, is commonly taken at 1 to 1.5 meters above the pavement merely as a matter of convenience, it being very difficult to use a photometer near the pavement in the street on account of traffic. The vertical component of illumination has practically seldom to be considered in street lighting, save in its effect on nearby buildings, a matter which will be considered presently.

Considering the nature of the problem of street lighting, that is, the illumination of a narrow surface extending in both directions from the source of light, it is obvious that the vertical distribution of light around the radius is a matter of great importance. A uniform spherical distribution is bad for the purpose, and the practical question regarding an illuminant for such use is how much of its effective flux of light can be conveniently turned downward upon the street. Light above the horizontal is not absolutely wasted, for it does some service by illuminating buildings. A radiant for street lighting should, however, be judged substantially by the lower hemispherical intensity, taking the lamp and its reflecting system together. Reflectors are useful with all varieties of street lamps merely for the purpose of deflecting downward light which would be otherwise lost toward the sky, and within limits the natural distribution from the source, that is, the distribution without any reflector, is a matter of no great importance, save as it may influence the convenient design of the reflecting system. A radiant which naturally and without a reflector casts a large proportion of its light into the downward hemisphere does not gain anything by that peculiarity unless it can show greater efficiency in lumens per watt than some other lamp with its reflector, or possesses important practical qualifications in its favor quite outside the matter of distribution. The modified distributions secured by the aid of reflectors are, however, like the distributions from the radiants themselves, generally symmetrical around a vertical axis. Only two of the illuminants used for exterior work have the valuable property of distribution unsymmetrical around the vertical, and hence are capable of being so oriented as to throw a relatively large percentage of light up and down the streets. These are the Nernst lamp and the mercury tube, neither of them extensively used for street lighting.

Praiseworthy efforts have been made toward securing by reflectors a distribution stretching up and down the street rather than radially in all directions. They have, I am sorry to say, made little headway as yet for reasons psychological rather than physical. They are apt to be somewhat awkward, which is a great disadvantage by day, and require the maintenance of rather exact adjustment in order to do the most efficient work by night. Obviously, one could not push this sort of redistribution too far lest he should get an illumination approximating that which might have been obtained by a pair of automobile headlights facing up and down the street from a pole top and giving a capital light at a distance, but little nearby. If, however, one could obtain a distribution which, instead of being circular, was an ellipse or similar figure having a major axis two or three times the minor, it would prove of great practical service in street lighting, but the improvement must not be at the expense of awkward appearance or require constant care in cleaning to keep up its efficiency. The modification of distribution is important from the standpoint of securing the proper spacing and height of lights. A distribution curve with its maximum 50° or 60° below the horizontal is disadvantageous in that it compels a lamp to be placed high in order to bring its zone of maximum flux of light out toward the radius of minimum illumination indicated by the power of the radiant. On the other hand, a maximum within 15° of the horizontal is almost equally bad, since then the most effective rays can generally be made to give the required minimum only from a lamp placed so low that considerations of avoiding glare make it undesirable. From a practical standpoint a maximum somewhere between 15° and 30° below the horizontal is most desirable, considering the available power and the permissible height of most commercial radiants.

These considerations bring one at once to the question of the spacing and height of lights for street lighting, and with this is inextricably bound up the troublesome question of large versus small units. Considering the usual circular distributions it is readily seen that, basing judgment upon the required minimum and average values along the street, small units have the advantage in the total intensity required to meet given conditions. This total intensity, assuming radiants of the same distribution curve and placed at the most suitable height, as indicated by equation 2 of the last lecture, varies apparently inversely with the square of the

number of units assigned to cover a given length of street. In other words, to double the effective radius of action of a light, preserving these conditions of symmetry, requires four times the intensity, and so on. A glance at Fig. 4 shows the condition of things: a is the radius of action for a given minimum for the source A, and b of similar radius for the symmetrically positioned radiant B_1; clearly, if a second small radiant B_2 be placed so that its radius of action touches that of its mate, one obtains from either disposition the same minimum illumination along the center line of the street, but the two radiants B_1 and B_2 need each give only one-fourth the light given by A. Moreover, since the

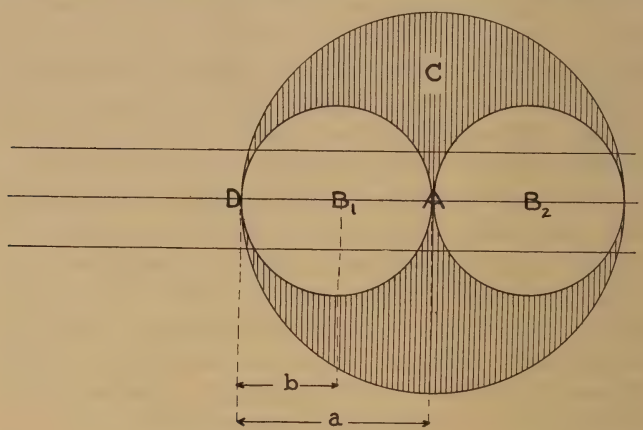


FIG. 4.

circle of radius A has four times the area of one of the circles of radius B the total flux per square meter is the same in either case if symmetry is preserved, and the average flux through the respective cones of distribution would be equal. If this rudimentary computation were all there were to the matter the case would be definitely settled in favor of small lights, but it is easy to see that this would lead to a *reductio ad absurdum.* For a single candle will give 0.5 lux at a distance of nearly two and a quarter meters, and one may easily imagine the general darkness of a sidewalk, for instance, illuminated by candles nearly 4½ meters apart. The secret of the matter is, of course, the great and useful flux of light required to give the fixed minimum intensity when using powerful illuminants.

In Fig. 4, if the light A, with its effective radius a, illuminates the circle of which it is the center, then the lights B_1 and B_2 equally illuminate their respective circles, but there is an equal shaded area C shown outside them which they do not light, and which is effectively lighted by the radiant A. Now, this large area is, from the standpoint of street lighting, not useless. If the houses stand well back from the street, it effectively affords them police protection, if they face close upon the street some of the extra light is reflected from their surfaces and again becomes useful either as lighting directly the street or as furnishing a bright background against which dark objects may readily be seen. In other words, while the minimum requirement, and even the average requirement, can be met by a much smaller total flux with small units than with large ones, the latter do in fact add greatly to the effectiveness of lighting for the purposes of its use. A light giving a total of 10,000 lumens and placed 8 or 10 meters high in a well-built street is likely to throw 2000 or 3000 lumens on the surface of the buildings from which 15 to 25 per cent will ordinarily be reflected, adding, therefore, very materially to the total illumination and affording a most excellent background for vision.

Still further, if we replace one large light by n small lights under the assumed conditions, we not only get but one n, the total flux for the same minimum, but we have to install and maintain n lights instead of one, and since the investment and maintenance charges make up a large proportion of the total cost of any street illuminant it often turns out that in an attempt to gain illuminating efficiency by decreasing the spacing and using small lamps there is no reduction in total cost commensurate with the loss of light flux. It is on this practical condition that the choice between large and small units usually depends. Also, if a certain minimum illumination be set, and a source of large power be replaced by smaller sources, these cannot be placed as B_1, B_2, B_3, B_4, Fig. 5, with their circles of limit illumination merely tangent, for that leaves much of the street below the allowed minimum. They would have to be placed over-lapping, like B_5, B_6, B_7, B_8, or else the effective radius of each lamp must be multiplied by $\sqrt{2}$, i. e., the power of each smaller radiant must be practically doubled, so that in the long run the small radiants again gain little in the practical flux required. Without going into the analysis of the require-

ment of over-lapping enough to cover the street at the required minimum, it is apparent that the economy in flux secured by using small sources is much smaller than at first seems plausible, and the gain in cost smaller still. In point of fact, small sources are advantageous chiefly in second-class and third-class lighting. For first-class lighting they will rarely be found at all economical.

In thickly built-up and important streets the enormous light flux from powerful light sources is so useful for the general purposes of illumination that it pays to employ them. Particularly is this the case since it is true both in gas and electric lighting that the very large units are of very much higher efficiency than the small

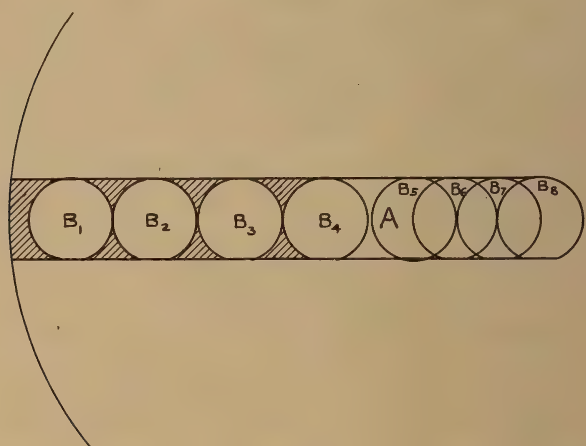


FIG. 5.

ones. On the other hand, in streets requiring only moderate illumination, and particularly in streets low hung with shadowing trees, the small light, which for efficient use must be hung rather low, as we have seen, is greatly to be preferred. In streets of the third-class, where every effort is being made to make a little illumination go a long way in point of usefulness, and where the conditions are such that there are no lateral reflecting surfaces to be utilized, the small unit is imperative. In every-day practice, especially with electric illuminants, the distribution curves of the small incandescent units and the much larger arc units, even when both are modified with the best available reflectors, vary very ma-

terially, so that in practice it is desirable to draw curves like L_n (Fig. 1), giving illumination as a function of distance according to the lamp, and thus make graphic comparison of the relative results to be obtained from the two classes of illuminants in service. When installed in diffusing globes both arc and incandescent lamps, and gas lamps as well, tend to a rounded type of distribution, which makes reflectors necessary to secure maximum efficiency. As a rule, all illuminants in American practice are mounted lower than they ought to be for efficiency, that is, lower than the point at which the form of distribution curve is utilized to the best advantage. Powerful arcs or equivalent gas lamps should be mounted at least 8 or 10 meters above the pavement, and with the very large units even considerably more, up to 15 or 20 meters. Lamps of the type of the larger incandescent electric units and the corresponding gas lights need to be carried to the vicinity of 5 meters high for economical results, varying somewhat with the type of reflectors employed. Practically at the present time one has to choose between radiants giving, say, 50 to 100 candle-power, on one hand, or between 500 and 1000 on the other, only a few commercial sources running to still larger powers. In designing street illumination one virtually has to elect between using sources of the one or the other of these types. This choice once made, the considerations already given show the spacing which must be maintained in order to give the minimum illumination and the average illumination, respectively, suitable for the various classes of work, and the characteristics of the lamps used hold this spacing within narrower limits than seems at first sight probable.

In much first-class lighting extra light received from shop windows and signs affords valuable reinforcement during the hours when most light is needed. This illumination is very commonly as great as that from the street lamps, and sometimes several times greater. It is useful, but one cannot safely count much upon it, since it is largely influenced by habit.

In placing lamps, large or small, it is imperative that they should be so located that their useful light flux can be utilized. This condition is often violated by placing lamps where their light is very largely cut off by trees. By far the best method of placing street lamps from the standpoint of illumination is the cross-suspension. A street adequately lighted by lamps upon cross-suspensions may

often fail of it when side posts are used. Nevertheless, owing to local conditions and a certain dislike for cross-suspensions, noticeable in American practice, it is more general to use side poles. If powerful lights are used in streets which must be equipped with side poles, long mast arms, ugly as they are, are practically extremely useful. In fairly open streets lamps bracketed out from 2 to 6 or 8 feet from the curb give satisfactory results, and these methods of suspension are available for all illuminants, electric or other. Where there are many trees small units bracketed fairly well out from the curb are by far the most successful illuminants, although there may be local reasons for preferring larger ones in cases where rather brilliant lighting is necessary, and there is practical or aesthetic objection to increase in the number of posts. In final warning in the matter of spacing and height, it must be said that only a few of the most powerful sources, as yet very little used in this country, are capable of giving the illumination required for first-class streets over a radius of as much as 150 feet. Ordinary arcs spaced at 400 or 500 feet, as is too often the case, are rarely adequate, even for second-class lighting, on account of the long and very faintly lighted spaces which must exist. Only the most powerful radiants should be thus spaced.

The proper placing and screening of lights to avoid glare is another important matter. Glare is due to a number of causes, but practically it is chargeable to use of sources of too great intrinsic brilliancy, or too great absolute intensity at short distances. A powerful light, even at moderate intrinsic brilliancy, when viewed at short range floods the eye with light to an extent that interferes seriously with vision. It also cuts down the pupillary aperture to half or one-third of its normal value, which greatly diminishes the visibility of the less brilliantly illuminated part of the field, and more than anything else it spoils the dark adaptation which makes enormously greater difference than anything due to pupillary reaction. At considerable distances there is very little trouble due to intrinsic brilliancy, for when the retinal image falls to the dimensions of one or a few cones the pupillary and other reactions are slight and it matters little whether the light is in a clear globe or screened by a diffusing one. As, however, one is constantly coming into close range with street lights, protection against too high brilliancy is imperative in case of powerful radiants, either gas or electric. The smaller lights sending much less luminous

energy to the eye produce less disturbance by their glare, and diffusion, while desirable, is less necessary, save when one falls to third-class lighting, in which dark adaptation is all important. No trouble would be experienced with any ordinary illuminants if screened behind mildly diffusing globes. Unless lights are so screened the minimum illumination must be raised very materially for the same ease of seeing.

Owing to the comparatively weak illumination in most street lighting, methods of measuring it are somewhat troublesome. There is always difficulty in photometry with very weak light on the photometer screen, and this is aggravated in street work by frequent unsteadiness of the lights, and in some cases by their great difference in color from the lights used as comparison standards in field work. Comparisons of illumination near and below the minimum specified for second-class lighting are peculiarly fallacious, owing to the disturbing effect of varying adaptation. Indeed, it is not putting it too strongly to say that comparisons of such kind, say at 0.2 or 0.3 lux and below, are unreliable, even when made with the best available field photometers. Consistent results may sometimes be obtained by a single observer, or by two observers so used to working together that their results are in no wise independent, but consistency is no proof of reliability.

Acuity photometers sometimes used for such cases are even worse, and their results are not worthy of serious consideration as expressions of anything more than individual opinion. These instruments violate the fundamental rule of physical measurements, that when $\frac{dx}{dy}$ is large, y is unsuitable for determining x. And acuity varies from about 3 to 1 while illumination is passing from about 300 to 1. By all means the most reliable method of determining illumination is, in my judgment, computing it from the known distribution curves of the radiants, taken not with carefully cleaned and adjusted lamps under laboratory conditions, but with lamps in their ordinary service condition run from the commercial wires or gas mains, even though tested in the laboratory. The effect of dirt on the enclosing globes is so serious that it must be taken into account in this way.

For similar reasons the intercomparison in the field of different street illuminants is very unsatisfactory. One can tell photometrically pretty nearly what a light is doing, and can judge in a gen-

eral way of the effectiveness of that particular lamp. He cannot form, however, a correct judgment of the relative performance of two lamps of different kinds unless they are conspicuously different from each other, since he does not know ordinarily whether each of the lights is burning under its normal conditions, whether one of them is ill adjusted, and with a globe considerably dirtier than the average, or whether the other has been carefully adjusted to give more than its normal duty, and is as clean as care can make it. Of course, anyone can tell a clean globe from a dirty globe, but he can do nothing more than guess how much difference to ascribe to this cause. I have personally seen in my capacity as consulting engineer a good many cases of skilful and unscrupulous jockeying with lamps, and even with the photometry of lamps, and I am unhesitating in the opinion that while field comparisons may be interesting as experiments they do not form a suitable basis on which to found lighting contracts which may involve hundreds of thousands of dollars during their terms. And particularly is this stricture directed at reading tests so called, at low intensity, which are largely matters of adaptation and adroit manipulation of the conditions. It would be too severe to say that they are commonly applied with intent to deceive, but it is well within bounds to say that they are generally open to suspicion, whether directed by the contractor for illumination or by critics inclined to be captious. They are sometimes called "practical," but experience has taught me to define a "practical" test as a test cunningly devised to divert attention from the objectionable points of the thing tested. Their proper sphere is merely to furnish one item of information, and not a very important one, about what the lights are doing. Two lights, both in good condition and adjusted and operated by impartial observers, can be compared in the field with a reasonable degree of precision, but never any more satisfactorily than they can be compared under properly arranged laboratory conditions.

To summarize briefly the characteristics of modern illuminants for street service one may divide them into five generally familiar types: 1, flame or luminous arcs; 2, carbon arcs; 3, tungsten incandescent lamps; 4, high-pressure mantle gas lamps; 5, low-pressure mantle gas lamps. Inasmuch as the two latter classes will be described at some length by one of my colleagues, I need say no more here than that the high-pressure gas lamps are powerful illuminants comparable in intensity to the flame arcs, that is, run-

ning from, say, 1000 to 3000 candle-power, and of sufficiently good color and steadiness to meet all street requirements. The low-pressure mantle gas lamps are usually of 100 candle-power or less, like tungsten incandescent lamps, and when properly maintained bear the same relation to the high-pressure lamps that the incandescent lamps do to the arcs. Considered merely as radiants for the street, they have no peculiarities of color or distribution which separate them from other radiants.

The flaming or luminous arcs are of three general classes: 1st. Arcs burning carbons of which one or both are mineralized, commonly with calcium fluoride for yellow light or with other substances for a whiter light, with converging carbons pointed in an acute angle downward. 2d. Vertical carbon flame arcs, commonly known as the system Blondel lamps, burning similar carbons heavily mineralized and in vertical position. 3d. Lamps burning electrodes, at least one of which is charged with metallic oxides, most commonly oxides of iron and titanium in various proportions. Such are the magnetite arcs in common use. In this case the positive electrode is of copper and the active mineralized one is an iron tube packed with the oxides. All these lamps may run to high powers, from 1000 to 2000 or 3000 candle-power, in the effective zones of the lower hemisphere, and with mean lower hemispherical candle-power ranging up to 2000 or more. The converging carbon lamps from the position of the electrodes tend to throw the light downward, to an extent that is not readily corrected by reflectors. They should hence be placed specially high with respect to the spacing. They are reasonably steady and have proved very satisfactory illuminants. The vertical carbon flame arcs give a distribution which lends itself rather more readily to the successful use of reflectors, and the maximum light falls, with properly designed reflectors, within the useful zones from 15° to 30° below the horizontal. They are, on the whole, more efficient for street service than the converging carbon lamps, and they are made even up to 3000 candle-power and more. The lamp described with reference to the lighting of Copley Square in the previous lecture is one of this class, and gives a maximum of about 2500 candle-power, including the opal globe, in average condition, at the angle of about 15° below the horizontal. This advantageous distribution is due largely to a well-placed reflector. The specific consumption of the large flame arcs of both varieties is somewhere

in the region of about one-quarter to one-third watt per candle. The metallic oxide lamps have for their chief advantage a rather long-burning electrode, giving within a reasonable length of pencil of 8 or 10 inches a life of 50 to 150 hours. The products of combustion being brownish oxides tend to smut the globes, and have to be gotten rid of by special draft channels which carry the fumes away. The commonest of this type is the so-called magnetite lamp, which has proved extremely successful as an illuminant in practice. Its specific consumption, when put in a light opal globe, ranges in the region between one-half watt and one watt per candle, according to current as in other arc lights. It furnishes a suitably steady light in the vicinity of 1000 hemispherical candle-power in the moderate sizes, and nearly as much again as an extreme figure. The color is good and the steadiness adequate, and the lamp has been rapidly driving out the older forms of arc, being preferred to other flaming arcs in this country on account of the long life of the electrodes. The magnetite lamp is operated at from 4 to 6 or 7 or even 10 amperes, the latter rarely, and the voltage at the arc is about 80. These characteristics make it very convenient for use on series circuits.

Ordinary carbon arcs are becoming obsolete for street service. They run in sizes from 600 or 800 mean hemispherical candle-power to as low as 200 or 250. The former figure belongs to the few powerful open arcs that are in existence, the latter to some of the alternating-current enclosed arcs. The specific consumptions range from a little better than 1 watt per candle in the former case to fully 2 watts per candle in the latter.

The tungsten incandescent lamps are perhaps too well known to need comment here. They are ordinarily available in candle-powers from 40 to 100, and lamps of 200 or 300 or even 400 candle-power have been produced, but have not sufficiently commended themselves to the art to come into material use at the present time. The tungsten lamps form the main reliance of street electric incandescent lighting at the present time. Their specific consumption is in the vicinity of 1¼ watts per candle, and their distribution, when suitably equipped with reflectors, well suits street lighting. The carbon incandescent lamp, like the open-flame gas lamp, is rapidly becoming obsolete.

Contracts for street lighting are essentially contracts on the part of a public supply corporation for service. A city does not buy merely

a given number of kilowatt-hours per annum, nor a specified number of arc or incandescent lamps of certain candle-power. It does buy, in fact, light and service with specified illuminants, including current or gas, as the case may be, maintenance of the lights in first-class working condition, and the operation of them for certain specified hours per year. It is the character of the service that determines the difference between good and bad lighting. One may specify a certain consumption of gas or of watts in a lamp and still get extremely bad service. He may also specify a certain minimum illumination and get extremely bad service. If he tries to buy illumination as such, he faces the practical impossibility of measuring it with sufficient precision for the maintenance of contractual relations. He can tell with the photometer whether the lights are performing well or badly, but he cannot by any means estimate the faint illumination customarily used in this country as a minimum with a degree of precision that should pass any conscientious auditing department. Buying and selling illumination as such is simply courting litigation. The soundest basis for a contract between a supply company and a municipality for street lighting is for service during specified hours per year, and with proper allowances for outages, of specified types of lamp, the characteristics of which can be evaluated, such lamps being placed in accordance with the requirements of the city. If they are placed so as to meet such requirements of illumination as I have previously set forth, and are properly maintained by the operating company, the illumination will be found adequate and its value can be on the average reckoned from the known characteristics of the lamps with far greater precision than it can be measured on the ground. The location of the lamps should be done under the direction of the municipality so as to produce the illumination required, but if any definition of the illumination is specified, both the minimum and the average should be included. Lighting on the basis of a contractual minimum only is, and is intended to be by at least one party to the contract, bad lighting. Judging by average illumination alone is merely an incentive to unequal distribution, but when the illuminants themselves and the terms of their output and operation are properly specified the illumination will take care of itself.

XIV (2)

PRINCIPLES AND DESIGN OF EXTERIOR ILLUMINATION BY GAS

By E. N. Wrightington

CONTENTS

Division A—Street Lighting

- Street signs.
- Boulevard types of to-day.
- The burner and its accessories.
- Automatic controller.
- Diaphragm regulator.
- Efficiencies.

Vapor street lamps.

- Used in outlying sections.
- Early open-flame type.
- Mantle burners, early and final types.
- Fuel used.

Inverted mantle burners.

- Boulevard type.
- Foreign types.
- Efficiencies.
- Cost of operation.

V. TYPES OF GAS STREET LAMPS—HIGH-PRESSURE GAS.

History of introduction.

- Upright burners.
- Inverted burners.
- Press gas vs. press air.

Some notable installations.

- Berlin.
- London.
- Conclusions of Street Lighting Committee.
- Westminster lighting contract.

Efficiency.

- English type.
- German type.

Cost of operation.

Introduction into this country.

VI. AUTOMATIC LIGHTING AND EXTINGUISHING OF GAS STREET LAMPS.

Types in use.

- Clock lighters.
- Pressure lighters.

Present examples.

VII. MISCELLANEOUS.

Maintenance of candle-power efficiencies.

Physiological advantages.

Division B—Other Outdoor Lighting

Arc lights.

Portico lights.

Division C—Conclusion

DIVISION A—STREET LIGHTING

I. History

Introductory. With the constant growth of the world's business and social interest, there has been a continual demand for increased facilities to provide for their needs. We have long since passed the time when the community's activities ceased with daylight—the days when shutters were put up and doors bolted, when travel at night on the streets was infrequent, and if at all, was accomplished by means of lighting the way by torch-bearers. Civilization's progress has made the lighting of streets a public necessity for the safe and convenient extension of business and social intercourse.

In common with other institutions street lighting has passed through various stages of evolution from the days when by municipal edict, property holders were required to hang out lanterns from their buildings, up to the present time when the municipality itself assumes the responsibility and expense of providing for the lighting of its streets.

Pitch, 1558; Oil, 1766. Up to the middle of the sixteenth century those who found it necessary to use the public ways by night were dependent upon the moon, or a torch or lantern carried by hand. Probably the first attempt on the part of municipal authorities to undertake the public lighting of the streets was by the City of Paris about 1558, when, at public expense, in the most important thoroughfares, large metal receptacles or vases, filled with pitch or resin, were kept burning during the night. This means was employed until about 1766, when oil lamps were substituted.

Gas First Used in Paris, 1818. In 1818, very soon after the use of gas in a practical form as an illuminant was discovered, gas street lamps made their first appearance on the streets of Paris. The substitution of a new street illuminant for older forms was very gradual, as evidenced by the fact that in 1829 there were then only 40 public gas lamps in Paris, while 3000 oil lamps were still in use.

Gas First Used in London, 1813. Gas street lighting obtained its start in London during the years 1813 and 1814.

Gas First Used in America, Baltimore, 1821. In America, Baltimore was probably the first city to have gas street lamps, in 1821.

Gas First Used in Boston, 1822; New York, 1823; Philadelphia, 1832. Boston followed in 1822, and in 1823 the municipality of New York made a contract with the New York Gas Company for gas lamps on the streets south of Grant Street. Philadelphia did not begin to use gas for street lighting until 1832, although it was in that city that the first application of gas lighting in America to interior illumination was made by the lighting of the New Theater, on November 18, 1816.

Generally in Use after 1836. By 1836 gas was becoming very generally used for street lighting throughout the country. The sperm oil and kerosene lamps were gradually replaced by gas lamps which had distinct advantages over the other types, and marked an important advance in efficiency of street lighting.

Flat-Flame Burner, 1836 to 1880. Carburetting Tanks to Increase Candle-Power. The early installations were, of course, entirely with the flat-flame burner, at consumptions ranging from 3 to 8 cubic feet per burner per hour. Where a considerable amount of light was required, as in principal business streets and street intersections, lanterns containing a number of burners were used. In London, between 1850 and 1860, numbers of street lamps were equipped with carburetting tanks containing light volatile oils through which the gas passed before reaching the burner, and becoming thereby enriched, produced a higher candle-power light. Before this system was very much extended, however, improvements were made in the manufacture of the gas so that instead of having only 9 to 12 candle-power, it produced from 14 to 20 candle-power.

Electric Arc First Introduced, 1880. From 1836 to 1880 gas held the lead over other forms of street illuminants, but in 1880 the first electric arcs in America were introduced, and shortly after came the electric incandescent carbon-filament lamp. The intense light of the electric arc soon brought it into favor, and in a few years it took the place of gas in the business districts where traffic required high candle-power light sources, and as few obstructions in the form of lamp columns as possible.

Incandescent Mantle First Introduced, 1890. Incandescent Mantle First Applied to Street Lighting, 1896. At the same time that the electric arcs were being introduced, Dr. Carl Auer von Welsbach was making interesting and valuable investigations into

the radio-active qualities of some of the rarer earths when brought into the non-luminous flame of the Bunsen burner. After 10 years of experimenting he produced his incandescent gas mantle made of the oxides of thorium and cerium. This was in 1890, and when the collodium coating process was perfected incandescent mantle gas lighting became a practical fact. It seemed almost impossible that so delicate a fabric could be successfully employed for street lighting, but in 1896 the first contract for such lighting in America was made. Between the electric arc and the four-fold efficiency of the incandescent gas mantle, the days of the old flat-flame gas street lamp were numbered.

Inverted Mantle Lamps. Within more recent years, especially in European cities, the inverted mantle burner has been brought into the field of street lighting. It has the advantage over the upright mantle burner of greater efficiency per cubic foot of gas consumed, and the mantle is smaller and stronger. For street lighting purposes it has the disadvantage of a rather elongated distribution curve directly below the lamp in the vertical plane, necessitating a greater mounting height in order to extend its illuminative zone.

High-Pressure Lighting. The most recent improvement in gas street lighting has been the development of high-pressure gas. The first installations were of the upright type, but later examples embodied the use of the inverted burner. Units up to 4000 candle-power are now being successfully used in cities of Continental Europe and England. Thus gas for street lighting has kept up with the progress of the times, and the citizen of the ancient days, dependent upon his torch or lantern to guide his progress through the night, would be as much startled to see a street lighted by these high-pressure gas lamps, as he would in witnessing many other of our modern inventions and institutions.

II. Requirements of Good Illumination

Evolution from Beacon Lighting. Along with the improvements in illuminants came the ever-increasing demands for more and better street lighting. In the former days street lighting consisted of a row of beacons of small illuminating power, marking the direction of the streets and street intersections.

Abundance of Light Desirable. To-day the fact is established that health, morality, energy and intelligence are all enhanced by

an abundance of light, as surely as its absence indicates and encourages the presence of immorality, ignorance and crime. The proper lighting of a city's streets is as important as proper policing, and to be effective and efficient certain cardinal requirements must be observed.

Daylight Qualities Essential. Physiological Effect. Any artificial form of illumination should have as many of the characteristics of daylight as possible; that is, color-diffusing quality and uniformity. In street lighting the physiological effect must be studied so that the sensitiveness of sight shall not be impaired by sharp contrasts of light and shadow beyond the normal range of adjustment of the retina. The effect of passing alternately from one intensely lighted zone into one of darkness is blinding and bewildering, and is the effect most to be guarded against in the proper lighting of streets.

Incandescent Gas Mantle Particularly Suitable. The incandescent gas mantle meets these requirements with marked success. By its form and structure the diffusion of light from its surface is almost perfect. The large surface over which incandescence is spread results in a low intrinsic brilliancy to which the eye easily adjusts itself. The characteristic curve of light distribution from a Welsbach mantle in the vertical plane shows that the maximum intensity of light is emitted in a practically horizontal direction from the center. As the curve turns toward the vertical above and below the horizontal, the intensity gradually diminishes, reaching a minimum directly over and below the mantle. Owing to the tubular form of the mantle, practically the same distribution is produced in all directions in the horizontal plane.

From its form, the almost ideal color value of its light as compared with diffused daylight, the characteristic distribution of its light—which projects the most intense rays the greatest and the less intense rays the shortest distance from its position above the street—the incandescent gas mantle is an almost ideal illuminant.

Proper Spacing and its Limitations. Uniform horizontal illumination is the ideal toward which we should aim. We can approach this ideal by the use of large numbers of small units, or by the use of a light source having its maximum intensity only slightly below the horizontal, or by a combination of both of these methods. Unfortunately, the cost of maintenance and of investment of the large

number of small units is greater than of a less number of larger units, even when the total gas consumed by both systems is the same. We are, consequently, limited in our desire for the ideal illumination by the item of expense. The cost of the street lighting naturally devolves upon the municipalities, and city authorities, especially in this country, have not been sufficiently educated to the value of an adequate illumination of the streets to lead them to incur the necessary expense attendant therewith.

European Practice. In Europe the public funds are spent less grudgingly for street lighting. Instead of installations of incandescent gas lamps ranging from 150 to 350 feet apart, as in America, the posts are more closely spaced with due regard to the requirements of the different localities. Examples of satisfactory illumination are found in the incandescent gas lighting of the beautiful boulevards and public squares of Paris. The effect of the gas lighting in the Place de la Concorde, which brings out the beauties at night of the statuary and buildings, has been especially noted. Given a sufficient appropriation there is no reason why similar satisfactory results may not be obtained in this country by the use of gas.

Effect of Height. In considering the value of illumination from a light source for use in the streets, it is customary to give prominence to the horizontal illumination produced. At the same time the vertical illumination is also important in distinguishing approaching objects, such as vehicles and pedestrians. It is evident that within reasonable limits the horizontal illumination from most light sources at points some little distance from the lamp standard where it is most needed will be increased as the height at which the lamp is mounted is increased. This is especially true of inverted lamps on account of the character of the distribution curve. At the same time the vertical illumination is only slightly reduced at these distances as the height increases. The most desirable height to hang gas lamps is thus reduced to mechanical limitations, and it may be fairly said that gas lamps should be hung as high as possible, and at the same time admit of the attention necessary in renewing mantles, adjusting and cleaning. Of course, exceptions to this rule would have to be made where over-hanging branches of trees interfered with the illumination.

III. General Divisions of Street Lighting

Lighting of Business Streets. *Necessity for High Degree of Illumination—Large Units.* The intensity of illumination required in the business sections of a city depends, of course, upon the traffic, both by vehicles and by pedestrians. Fortunately, for municipal authorities, the conditions in this country of the business thoroughfares where all kinds of traffic are heaviest are such that public lighting to any great extent is not needed. The desire on the part of tradesmen to attract attention to their wares has led to a very brilliant window lighting, supplemented by outline lighting and signs. Most windows along the thickly traveled streets are so lavishly lighted that very little, if any, additional lighting supplied from the public funds is required.

This condition of street illumination is in marked contrast to the tendency in European cities. There are very few streets in such cities as London, Berlin and Paris where the shop windows are lighted at night. Usually a dark and forbidding shutter precludes all possibility of any wayfarer obtaining a glimpse of what the shop contains by day, and yet in the principal thoroughfares of these cities there is a constant stream of traffic, both on the sidewalk and in the street, which necessitates a high degree of street illumination. Naturally, this has to be supplied by the municipality, which, except in a few instances, receives very little, if any, assistance from the window lighting along the route. Such a condition as we find on Broadway, in New York, where the lighting from the windows and the illuminated signs makes the ordinary street arc look dim, is almost unheard of on the other side. On the other hand, our citizens would be equally surprised to walk down Fleet Street, in London, or Koeniggraetzerstrasse, in Berlin, and to note the high degree of illumination afforded by the high-pressure gas lamps.

Where artificial light is required in business streets of our American cities, the larger units are preferable, both on account of the greater intensity of illumination secured and of the less number of obstructions. These may be supplied with gas by low pressure by the use of a cluster containing two or more units, or by the use of single lanterns, each equipped with several mantles. By means of high-pressure gas, units may be installed anywhere from 500 to 4000 candle-power, spaced at whatever distance the density of the traffic may require and the public funds will admit.

Lighting of Residence Streets. *Lower Candle-Power Units.* In residence and suburban sections a high intensity of illumination is not needed. The smaller gas units will furnish sufficient illumination, provided they are properly spaced. There appears to be a mistaken tendency in such sections to adopt the larger units used in the main parts of the city, such as the electric arc, but, on account of the expense, installing them at considerable distances apart. The result is that between the lamps there is a very dark

Fig. 1.—Early Open Flame Type.

space not lighted at all, which, on account of the effect upon the eye of the intense light source, appears to be even darker than it is.

The bad effect of this kind of lighting is familiar to all who have driven through streets lighted in this way and have noticed how difficult it is to adjust the eye to conditions beyond each lamp after passing through the more brilliantly lighted areas. The ideal illumination of such streets is by gas units of moderate size, even if the amount of the street lighting appropriation will not allow of their being placed very near together.

IV. Types of Gas Streets Lamps—Low Pressure

Flat-Flame Burner. In the early days of street lighting, before the advent of the incandescent mantle, the flat-flame burner was used.

Upright Mantle Burners. *Early Apparatus.* The greater efficiency of the mantle burner soon resulted in the displacement of the old type of flat-flame burner. At first the regular style of frame lantern shown in Fig. 1 was used, but it was soon found

FIG. 2.—Early Mantle Type.

that it was not stiff enough to stand wind pressure; the top would leak during rain-storms and the old cup ventilator was totally inadequate. The first improvement in this way in America was in the form of the lamp shown in Fig. 2. The frame was made more substantial, the sides being more nearly vertical than in the old lamps, and to the top of the frame was fixed a rigid crown on which was placed an opal glass dome, and above this an improved ventilator. A door in the side of the frame enabled repairs to be made easily to the burner and to change mantles. The bottom of the frame was closed with a plate having a sliding door, through

which the lighter's torch could be introduced from the street. The glass dome, aside from its attractiveness, afforded an excellent means for shedding the rain and snow which ran down off the edges of the crown without streaking the glass sides of the lantern. The ventilator was carefully designed so that no gusts of wind could reach the interior of the lamp, and at the same time to increase the ventilation by carrying off the products of combustion in a proper manner under all weather conditions.

Fig. 3.—Mantle Lamp with Street Signs.

Street Signs. The rapid growth of cities and the never-ending demand for improvements to facilitate night travel on the cities' streets brought out the method of marking street corners by placing signs on the lamp posts. At first name boards were fastened to the lamp posts, but as these became defaced and lost, ground-glass segments with colored lettered street names were made a part of the street lantern, as shown in Fig. 3. This custom of using gas street lamps with street signs is common in Europe as well as in America. The accompanying views show a corner lamp in Berlin and one in Edinburgh, Figs. 4 and 5.

Boulevard Types of To-day. The improvement made over the old style of gas lantern by the one just described led to a still further change. The corners of the frame of the square lantern caused shadows, and in order to reduce these the boulevard globe type of lamp was designed. The experience with the square lantern showed that the more rigid the attachment to the lamp post of the lantern the less was the vibration, and, consequently, less shock to the mantle. Figs. 6 and 7 show the standard American type of

FIG. 4.—Berlin Type.

gas lamp of the present day. Being of cast-iron, it is more substantial than the tin and copper frame lamps; is impervious to rain or dust, has only two supporting arms, and can be more easily handled and cleaned. When repairs are needed the frame carrying the top and globe can be raised on the telescopic side arms.

The Burner and Its Accessories. The vital part of the incandescent gas lamp, the burner, was evolved only after considerable experimentation to obtain a suitable proportioning of parts to give the maximum light efficiency under varying gas conditions. It was

also essential that such a burner should continually give good service during its lighting times, and so arranged that it could be readily cleaned and adjusted by the class of labor employed to care for street lamps. Fig. 8 shows the burner and its accessories. The burner cock is screwed to the top of the service riser and inside the lamp directly over the bottom plate. A lock-lever attachment on the cock key permits of opening a gas way to the climbing lighter pilot, which is lighted at its lower end by the

FIG. 5.—Edinburgh Type.

lamp lighter's torch; then, by the ascending small flames on the edge of the tube, extending inside the glass chimney, the burner proper is ignited when the cock key is turned further on. The gas adjustment is made by needle screw into a fixed orifice while the air regulation is effected by turning a pierced metal air shutter around the Bunsen tube. The mantle with carrier and gauze is placed on the burner gallery and surrounded by a glass chimney. Above the glass chimney is an enamel chimney made adjustable and guided by a brass rod and sleeve. The entire equipment is such that it can be regularly cleaned and kept in perfect adjustment.

Automatic Controller. Where conditions exist of variable gas pressure, an automatic controller is used, taking the place of the needle-screw regulator. This device was especially designed for the purpose of delivering a constant supply of gas to the burner, at constant jet velocity, no matter how the gas pressure may vary in the service mains. It is so constructed that it can be adjusted to different gas gravities, and has been an excellent means of affording uniform results at all times.

FIG. 6.—Present Boulevard Type.

Diaphragm Regulator. In natural gas districts, as well as in a number of instances throughout the country where artificial gas is carried great distances, pressure, instead of being measured in inches of water, is measured in pounds per square inch. To meet these conditions, from 1 to 50 pounds pressure, a special form of metal diaphragm regulator is employed. This regulator is attached to the service pipe in the lamp and delivers the gas at its outlet into a small orifice jet at any pressure desired.

Efficiencies. The efficiency of the upright mantle gas lamp is about 20 mean lower hemispherical candle-power per cubic foot of gas. The efficiency is somewhat better than this figure at the useful angles for street lighting from 10° to 30° below the horizontal. The distribution of light in a vertical plane and the mean lower hemispherical candle-power are shown by the following table and diagram:

Single Burner Upright Gas Lamp

Distribution of Light in Vertical Plane

Candle-power at 20° below the horizontal. Outdoor Test
Average of all results .... 74 c. p.

Angle Below Horizontal	Outdoor	Indoor
10°	82 c. p.	
15	76 c. p.	
20	74 c. p.	74 c. p.
30	75 c. p.	
45	81 c. p.	
60	56 c. p.	

Approximate:
M. L. H. S. C. P....... 70.7 c. p.
Consumption .... 3.3 ft.
C. P. per foot 20° angle.................. 22.4 c. p

See Fig. 9.

This test was made on a lamp in which a small reflector forming an extension of the enamel chimney of lamp was employed. An improvement in efficiency of about 15 per cent at the effective angles was obtained by means of this device.

Vapor Street Lamps. *Used in Outlying Sections.* We have dealt so far with the lighting of streets along the lines of gas mains, but there are many cities of size which are not equipped in some sections for gas or electric lighting, and which sections it is necessary for public safety and convenience to have lighted. Generally speaking, these districts include the parks, suburban roads and the alleys.

Early Open-Flame Type. Prior to the adoption of the incandescent mantle for street lighting, a self-generating vapor lamp was designed to meet the demand for suburban lighting. It consisted of a lantern with a tank attached to its upper side and a plate burner, using as fuel naphtha or gasoline. By converting the liquid naphtha into a vapor by means of heat and by mixing

air at the burner, a good, yellow light of 16 to 20 candle-power was obtained, which burned continuously without smoking when properly adjusted. As a matter of fact, for a time this lamp became a competitor with gas in street lighting.

Mantle Burners. Early and Final Types. After the incandescent mantle came into use in gas street lighting, public necessity again demanded more light in the district lighted by the plain naphtha lamps. This demand was met by the design of a burner

FIG. 7.—Boulevard Type with Street Sign.

still employing the principle of vaporizing naphtha within the burner itself, but differently constructed from the plate burner so that it would produce a non-luminous flame within a mantle.

Some lamps were designed and used to some extent which heated the oil, under pressure, in a retort directly over the mantles.

As this system needed constant attention when in use, it did not become a factor in street lighting. A burner was finally evolved which has demonstrated its reliability under most severe conditions. The old-fashioned naphtha plate burner, being a luminous flame, required only sufficient primary air to support combustion

of the flame without smoking so that the vaporizer and jet could be closely placed to the flame, thereby keeping the vapor hot until it was consumed.

To produce a non-luminous or Bunsen flame with naphtha vapor requires a large percentage of primary air. To obtain this, it is necessary to have the jet considerably further away from the flame, so that a proper mixing of vapor and air is obtained, but in doing this the vapor must not be chilled or it will condense again to

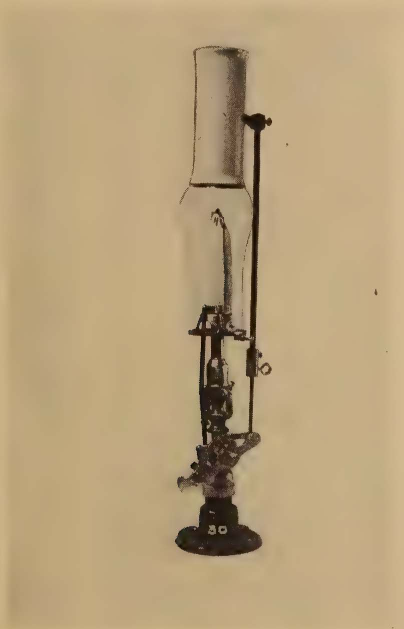


Fig. 8.—The Burner and its Accessories.

liquid. The burner body is cast brass with drilled passages and surrounded with a tube shield. The oil enters the burner from the packed tube at a fixed rate determined by the height of oil tank above burner, and the length and packing in the tube. From the inlet the oil passes up a channel to the vaporizer near the top, the vapor then descends to the lower part and issues from a small jet at high velocity into the Bunsen tube, drawing in sufficient air to produce a Bunsen flame, and finally burns above the gauze within the incandescent mantle. A portion of the vapor and air mixture issues from the parts in the Bunsen tube into an

annular chamber around the lower part of the Bunsen head, and is burned above small gauzes around the vaporizer. This maintains a constant vaporizing heat, and also keeps the burner channels warmed considerably above the condensing temperature of the vapor. These auxiliary flames, or subjects, being close to the mantle flame, are thus always kept lighted. The surrounding brass shield serves to conserve the heat of the burner, and guards against the temperature lowering effect of the air taken in for the Bunsen

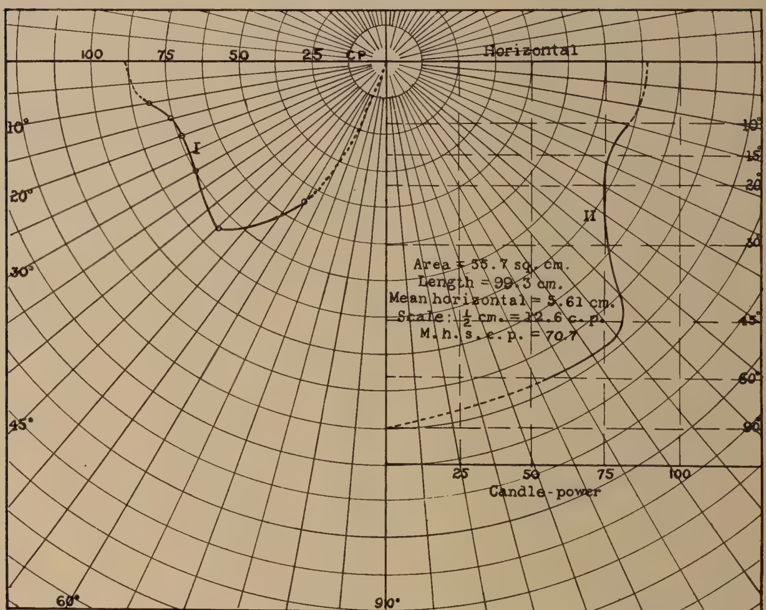


FIG. 9.

WELSBACH LAMP.
I. Curve showing the distribution of light in a vertical plane.
II. Rousseau diagram showing the mean hemispherical candle-power, based on Curve I.

mixture. The burner is lighted by preheating with a pressure torch, as in the case of the plate burner.

Figs. 10 and 11 show the naphtha incandescent street lamp equipped as it is used in America to a very large extent, and it has been a most satisfactory means for suburban, park and other isolated lighting.

Fuel Used. The fuel used is naphtha of 60° to 63° B. gravity, and from the high available heating power a candle-power in excess of 60 candles is obtained with mantles of the same size as those used for the gas street lamp.

Inverted Mantle Burners. On account of its greater efficiency the inverted burner has come into prominence in late years, especially in some of the European cities, notably in Berlin. The natural tendency is toward too much concentration of light imme-

FIG. 10.—Boulevard Naphtha Lamp.

diately below the lamp, where, on account of the distance, a great intensity is not especially needed. By raising the height of the burner from the street, however, a very satisfactory distribution is made possible. The distribution curve may be lengthened out in directions approaching the horizontal by the use of reflectors.

Boulevard Type. An arrangement is now being used in the so-called "boulevard" type of lantern, employing two small inverted mantles spaced higher in the lantern than the upright mantle. This device has produced, with a consumption between 5 and 5½ cubic feet per hour, a satisfactory distribution with an effective efficiency of about 30 candle-power to the foot.

Foreign Types. One foreign type consists of a japanned iron casing, drop-shade holder and globe, outside lever for main burner and pilot control, regulating cock on the outside and necessary pipe connections. The gas valves are of the needle type, and the air regulator of the sliding-band kind, with port holes.

As in the upright burner, the gas enters the Bunsen through a small orifice, and by its velocity draws in air through the air holes. The mixture of gas and air takes place in the burner tube below the

FIG. 11.—Naphtha Lamp with Street Sign.

air passage, and the inverted Bunsen flame, with characteristic light-blue inner cone and darker mantle flame, burns at the lower end of the burner tube, and inside the cup-shaped mantle which hangs from the tip of the tube, and which is heated to bright incandescence. The horizontal plate separates the burner tip from the lamp body above, in which the Bunsen tube and the air and gas adjustments are located.

The hot products of combustion ascend upward through separate tubes leading from holes in this plate directly over the mantle, and are discharged at the top of the lamp casing. By this means

the supply of oxygen to the air holes and mixing chamber is kept free from the exhausted products of combustion.

This burner is in single form, or in any groups of 2, 3, 4 and 5, and is enclosed in a metal cylindrical casing, and properly pro-

Fig. 12.—Inverted Lamp with Extension.

tected from winds and draughts by suitable screening of the chimney orifices. In this type a small pilot light burns, fed by a small tube leading around the main valve controlling the lamp, so that when the light is shut off the pilot is still supplied. The pilot

leads from a special valve, which is so arranged that the pilot is extinguished when the lamp is lighted, thus eliminating the small usage of gas by the pilot during lighting hours.

There is a special lighting attachment to allow the lighting of the lamp from outside without opening the globe, and without resort to the pilot. This attachment consists of a tube leading upward from a point just above the burner to the outside of the lamp. When the gas is turned on a small amount passes into this tube at the lower end, mixes with the air of the tube, and comes out at the upper end outside of the lamp. A flame applied here ignites the mixtures of gas and air, and the flame travels downward to the burner, which is at once lighted. See Fig. 12, photograph of single-burner inverted lamp.

Efficiencies. The efficiency of these lamps is for one burner about 30 mean lower hemispherical candle-power per cubic foot of gas, and for the two-burner about 35 mean lower hemispherical candle-power. The following curves and diagram show the efficiencies and distribution of light in a vertical plane of the foreign types of the one- and the two-burner inverted mantle lamps:

Single Burner Inverted Gas Lamps

Candle-power at 20° below horizontal. Outdoor Tests.
Average of all results.................... 94.5 c. p.

Distribution of Light in a Vertical Plane

Angle Below Horizontal	Outdoor	Indoor
0°		73 c. p.
10	98 c. p.	86 c. p.
15	96 c. p.	90 c. p.
20	99 c. p.	95 c. p.
30	117 c. p.	102 c. p.
40		121 c. p.
45	135 c. p.	
50		127 c. p.
60	137 c. p.	126 c. p.
70		124 c. p.
75	161 c. p.	125 c. p.
90	165 c. p.	127 c. p.
M. L. H. S. C. P......	118 c. p.	105 c. p.

Gas consumption per hour................ 3.66 ft.

Candle-power per foot:

M. L. H. S. C. P......................... 28.7 c. p.
At 20° angle .... 26.0 c. p.
Maximum .... 34.7 c. p.

See Figs. 13 and 14.

These efficiencies could be much improved by the use of prismatic reflectors. Twenty per cent increase in candle-power at the effective angles could be secured, but it is questionable whether the care of the extra glassware necessary would make it desirable.

Two Burner Inverted Gas Lamp

Candle-power at 20° below horizontal.	Outdoor Test
Average of all results:	
In plane of mantles	153 c. p.
In plane perpendicular to plane of mantles	175 c. p.

Distribution of Light in Vertical Plane

Angle Below Horizontal	Outdoor	Indoor
0°		176 c. p.
10		195 c. p.
15		203 c. p.
20	186 c. p.	220 c. p.
30	205 c. p.	242 c. p.
40		252 c. p.
45	213 c. p.	
50		253 c. p.
60	230 c. p.	255 c. p.
70	232 c. p.	253 c. p.
80		251 c. p.
90	216 c. p.	257 c. p.
M. L. H. S. C. P.	193 c. p.	226 c. p.

Gas consumption per hour	6.6 ft.
Candle-power per foot, M. L. H. S. C. P.	34.3 c. p.
At 20° angle	33.3 c. p.
Maximum	40.2 c. p.

See Figs. 15 and 16.

Cost of Operation. Conditions will differ in various localities, but in Berlin, where there are a number of the two-burner inverted lamps installed, the statistics are as follows, from which the cost may be calculated.

	Days.
Inner chimneys last	118
Mantles last	33
Globes last	324

1 man cares for 60 lamps.

V. Types of Gas Street Lamps—High-Pressure Gas

History of Introduction. *Upright Burners.* The greatest advance which has been made in the use of gas for street lighting is in the application of gas, or gas and air, at the lamp under

pressure. Heretofore about 20 mean lower hemispherical candle-power per cubic foot was obtained in upright burners with gas at ordinary pressures of 1 5/10 inches to 2 or 3 inches of water. It is now possible to obtain an efficiency up to about 50 mean lower hemispherical candle-power with a pressure of about 55 inches. For a number of years London Bridge, Tower Bridge, Queen Victoria and other streets in London have been lighted by double upright mantle gas lamps, consuming 10 to 20 cubic feet of gas

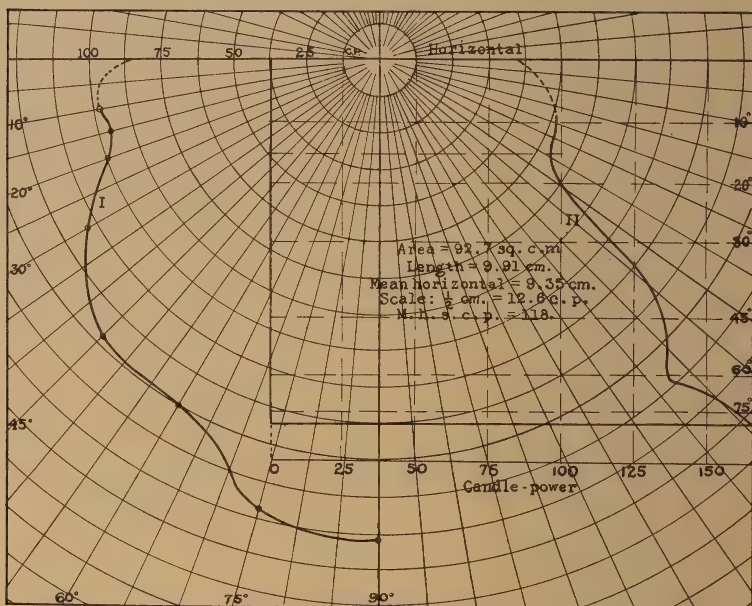


FIG. 13.

SINGLE MANTLE LOW PRESSURE GRAETZIN LAMP.

I. Curve showing the distribution of light in a vertical plane.
II. Rousseau diagram showing the mean hemispherical candle-power based on Curve I.

per hour, and producing a light of 300 to 600 candle-power at a gas pressure of 10 inches.

The necessary pressure is obtained by water-motor compressors in underground refuges near the installations, and supplied from there to the lamps by independent mains.

So satisfactory was this system of lighting that further im-

provements developed larger units of 1400 to 2000 candle-power, using gas at the rate of 36 to 48 cubic feet per hour, and at a pressure of 55 inches of water. This increased pressure was necessary for the larger consumptions in order to get perfect combustion, and to keep the burner parts as small and compact as possible. Compressors of the water-motor type were inadequate for the new high-pressure service, and direct-connected gas-engine compressors took their place.

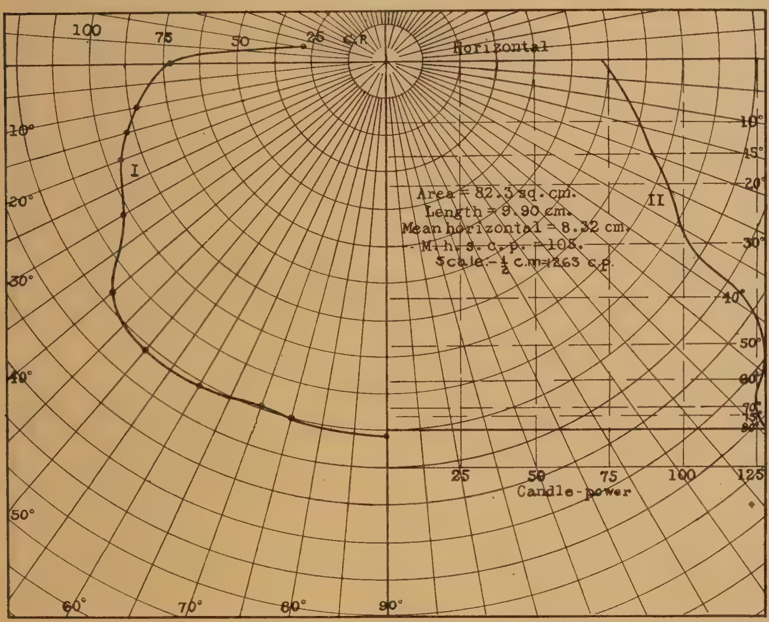


Fig. 14.

Single Mantle Low Pressure Graetzin Lamp.

(In Photometer Room.)

I. Curve showing the distribution of light in a vertical plane.
II. Rousseau diagram showing the mean hemispherical candle-power based on Curve I.

Installations of this type of lighting consist of mounting large hexagonal frame lanterns with glass sides on posts 16 to 18 feet above the roadway. Inside the lanterns are two burners and upright mantles, the latter being 1½ inches in diameter by 6 inches long, placed below the lantern center and surmounted by a large, slightly concave, enameled reflector having a draft tube in its

center to carry away the products of combustion. The burners are large, of the intensive injector type, equipped with automatic pilots, which are extinguished when the high-pressure gas is on.

Soon after this style of lamp was produced, Whitehall and Kingsway, London, and Alexanderstrasse, Berlin, were equipped with a number of them and demonstrated conclusively that high candle-power, efficient gas units are practical and the best form of illuminant for intensive street lighting.

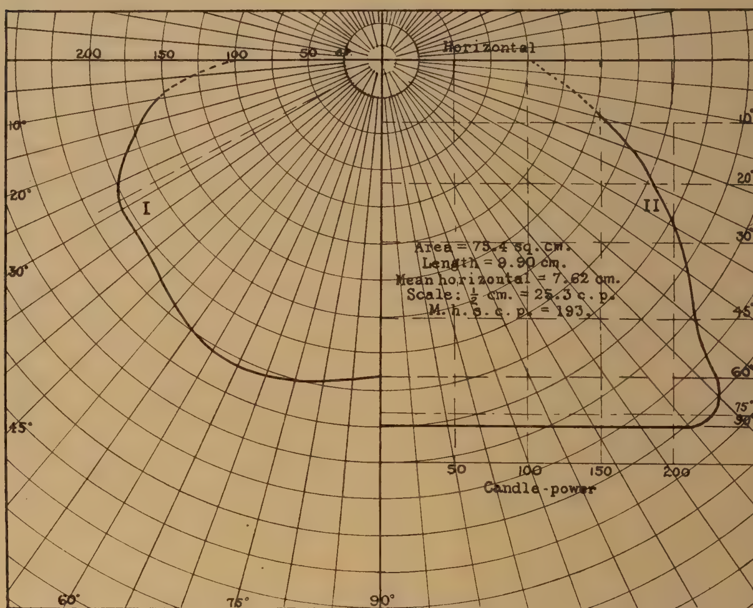


FIG. 15.

TWO MANTLE LOW PRESSURE GRAETZIN LAMP.

I. Curve showing the distribution of light in the vertical plane of the mantles.

II. Rousseau diagram showing the mean hemispherical candle-power based on Curve I.

Inverted Burners. More recently, in the City of Berlin, after a few installations of the upright type, the inverted burner has come into use. The municipal authorities were prompt in acknowledging the pressing needs for a high degree of diffused illumination on important streets, and, for a considerable time, experi-

mented with various types of units in order to determine which would give the best practical results, as well as the most economical. The outcome of their investigation was that high-pressure gas was applied to inverted mantle lamps with the result that the efficiency of 40 candles obtained with the upright mantle type was raised to about 50 mean lower hemispherical candle-power per cubic foot of gas.

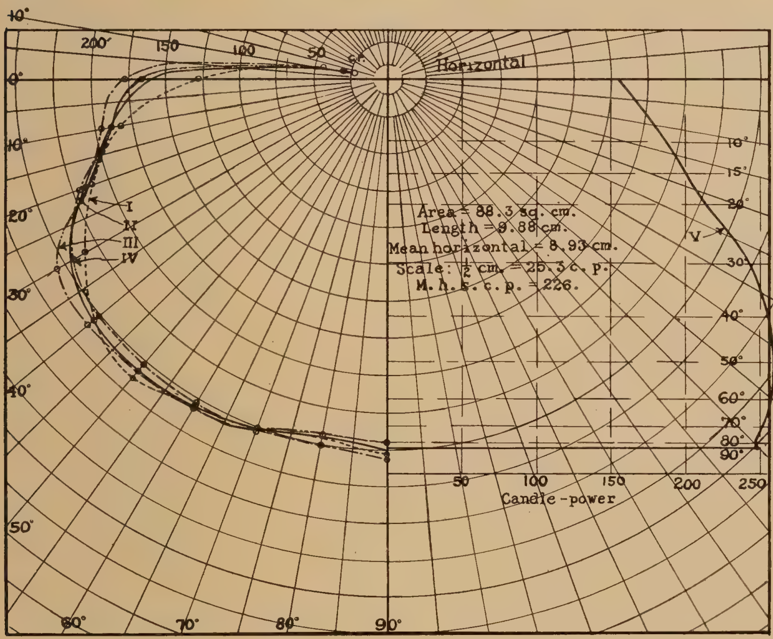


FIG. 16.

TWO MANTLE LOW PRESSURE GRAETZIN LAMP.
(In Photometer Room.)

I. Curve showing the distribution of light in the vertical plane of the mantles.
II. Curve showing the distribution of light in a vertical plane 45° from the plane of the mantles.
III. Curve showing the distribution of light in a vertical plane 90° from the plane of the mantles.
IV. Curve showing the mean of I, II and III.
V. Rousseau diagram showing the mean hemispherical candle-power based on Curve IV.

It was found that with high-pressure gas the distribution curve of the inverted mantle was improved for street lighting by having the direction of the maximum intensity raised nearer the hori-

zontal than is the case with gas at low pressure. This was an important discovery, as it made possible the installation of high candle-power units close enough to the street level to produce a high degree of illumination uniformly over a large street area.

The fact that the inverted mantles have greater structural strength than the upright, and can be placed on the burners in a soft condition and hardened by the flames on which they are to be used, are additional advantages. A great deal of difficulty was experienced in the early types of lamps intended for use with high-pressure gas on account of the high temperature, and the parts had to be made very strong and massive.

Various means of reinforcing the mouth of the burner had to be employed to prevent destruction on account of the heat. It was found that with high-pressure gas the mantle must come close against the mouth of the burner, as the combustion gases must be driven through the mantle instead of there being a space, as in low-pressure burners, between the mouth of the burner and the mantle, by which the products of combustion may escape.

At first the mantles used on the high-pressure lamps lasted only a very short time, barely half an hour. It was noticed that a fracture developed immediately beneath the iron ring by which they were attached to the nozzle of the burner, and it was found that the mantles had remained soft because they had not, at this point, been subjected to the strong heat. By experiment it was learned that if the mantle were put on the burners soft, or non-collodiumized, and allowed to burn off on the lamp itself, this fracture did not appear and the mantles had a much longer life. Other improvements have been made, so that while in the beginning of 1907 the mantles lasted only 2.8 days, they now last 11.3 days. The mantles are about 5 inches long and 1¾ inches in diameter. A similar difficulty was experienced in the breakage of globes. This was found to be due to the fact that the mantles at first, two of which were used in the largest-sized lamp, were so long that the globes were soon broken. Later, the two burners which consumed 42 feet of gas each were replaced by three smaller burners having smaller mantles, each consuming 28 cubic feet. Still more recently the consumption has been further reduced to 22 feet for each burner, with the same candle-power as before. The result of this improvement is shown from the fact that the

globes lasted at first only 55 days, and now last in the three-burner type 223 days.

The high-pressure system consists of an independent line of steel tube mains under the sidewalks, connected with compressor stations at the gas works. The stations are equipped with gas-engine-driven compressors, which raise the ordinary street pressure to 60 or 70 inches of water.

The large three-burner lamps are installed on posts 18 feet above the street and equipped with automatic devices for lighting and extinguishing when the pressure is changed from low to high pressure, as well as an independent valve operated by hand for opening or closing the supply of gas to any or all the burners. The glass globes are large in size and almost spherical in shape, the greatest diameter extending slightly beyond the edge of the shielding reflector. By this means a greater diffusing effect is produced.

The burner construction is massive owing to its having to withstand great heat, and is such as to produce a certain regenerative effect on the primary air mixture. Having a constant pressure at all times by perfect regulation at the compressor stations, a single fixed gas orifice is used with an adjustable air supply to meet all conditions of quality and gas gravity.

The lamp is so designed that after midnight when street traffic has diminished two of the burners are extinguished by hand, reducing the light and the gas consumption, and likewise the cost.

The effect produced by these lamps spaced 100 to 130 feet apart is the most remarkable in its close approach to diffused daylight. The diffusion of light is such that one can look up and down a street so lighted and see clearly and distinctly distant objects beyond and between lamp standards without the disagreeable effect of glare.

Press Gas vs. Press Air. In the early installations a mixture of gas and air was supplied under pressure, but the system was soon extended to compressed gas, pure and simple, which was found to give as high an efficiency as a mixture of air and gas, with the advantages that the pipes and the compressing plant could be smaller. Later experiments have led to reconsideration of the merits of the use of compressed air in separate pipes. It is said that there is apparently no particular advantage, as far as the

relative efficiencies are affected, in the use of the high-pressure gas as compared with compressed air. The use of the pressure gas is mainly for the purpose of drawing in with it a sufficient quantity of air into the burner in intimate mixture with the gas in order to provide for rapid and complete combustion. In fact, the actual pressure in the burner is not much above atmospheric.

For this reason some manufacturers introduce the compressed air direct to the burner through separate pipes. There appears to be some discussion as to the relative merits of the two systems. It is claimed, on the one hand, that by the use of compressed air the present system of gas pipe does not have to be altered or added to, and that commercial and street lighting can be supplied from the same gas mains. It is also alleged that the escape of pressure gas might lead to some danger. Although, of course, a separate system of pipes is likewise needed for the compressed air, it is stated that these may be installed at less expense.

On the other hand, it is contended that the installation of compressed air pipes requires as much care as the installation of pressure gas pipes, and that an escape of compressed air may not be discovered for some time and yet seriously affect the system, while an escape of pressure gas would be at once evident on account of the odor. It is also stated that ordinarily the existing gas mains will not be large enough for high-pressure work when used with the compressed air, on account of the larger quantity of gas required.

Some Notable Installations. *Berlin.* Pressure lighting has probably reached the furthest development at the present time in the City of Berlin, where there are installed 1678 high-pressure inverted gas lamps, comprising 4111 burners. There are also still in use 446 high-pressure upright lamps, comprising 770 burners. Perhaps the most striking example of the high-pressure inverted gas lighting is on the Koeniggraetzerstrasse. The units now in use on this street are of about 4000 candle-power, and consist of three burners each, two of these being extinguished at midnight.

They are hung at a height of 18 feet above the street level, at a distance of 139 feet apart, the width of the street being 94 feet. There are two gas mains on each side under the sidewalks. There is thus about 6400 square feet of street surface to each lamp. The consumption per hour of these lamps was formerly 84 feet, but has more recently been reduced to 65 feet. It is claimed that under

FIG. 17.—High Pressure Gas Lighting, Koeniggraetzerstrasse, Berlin.

practically the same conditions in a street 120 feet wide, with the posts set 131 feet apart, the maximum horizontal illumination would be 12.7 foot-candles. The minimum horizontal illumination would be 0.3 foot-candle, and the average 2.1 foot-candles.

It can therefore be readily imagined what the effect of such intensities of illumination would be. At the same time the large area of the three mantles contained in the light source, and the low intrinsic brilliancy, produce a very soft and pleasing effect, and not the glare that might be expected from lamps hung as low as these are. The accompanying photograph (Fig. 17) gives only a slight idea of the illumination.

The high-pressure system is being rapidly extended, and the municipality has recently decided to spend 7,000,000 marks in installing the high-pressure gas lamps of the inverted type in place of the existing gas and electric lamps.

The lamps to be used are graded according to the importance of the thoroughfares. At junctions of main streets lamps of 4000 candle-power, in the main thoroughfares lamps of 2000 candle-power, and in other streets lamps of 1000 candle-power.

London. The most important installation of high-pressure gas in London is on Fleet Street, where inverted burners are used in brackets hung from the sides of the buildings. These lamps are of smaller units than the largest lamps used in Berlin, and are rated at 1500 candle-power on a consumption of 25 feet. They contain a single burner and are of an English type.

Conclusions of Street-Lighting Committee. Other installations in London will undoubtedly follow, as a committee, which was appointed by the Streets Committee of the Corporation of London to study the lighting of Continental cities, has advised installations of high-pressure gas lamps. The conclusions of this committee, who visited the principal cities of Europe, namely, Brussels, Cologne, Düsseldorf, Berlin, Dresden, Vienna, Münich and Paris, are as follows:

1. That wherever possible streets should be lighted by means of centrally hung lamps with lowering gear.

2. That open spaces should be lighted by means of lamps upon standards fitted with lowering gear.

3. That high-pressure incandescent gas lamps with inverted burners should be adopted as the illuminant, but where gas is

impracticable electricity with open arc and flame arc lamps should be installed.

Westminster Lighting Contract. The City of Westminster in the east end of London has recently awarded a contract for lighting its streets by gas instead of electricity, as in the past. The streets affected are in the heart of the fashionable retail section of London, and include Regent Street, Piccadilly, St. James Street, Pall-mall, Piccadilly-circus, Whitehall, Victoria Street and Parliament Square.

High-pressure gas lights will be installed of a capacity from 1800 to 3000 candle-power. Smaller lights will be installed under low pressure. The prevailing type will be inverted. The system will be similar to that used in Berlin with special steel mains and compressing stations, but the lamps will be of English rather than of German manufacture.

Efficiency. *English Type.* The prevailing unit at the present time is a one-burner lamp consuming about 25 to 30 feet of gas per hour and rated at about 1500 mean lower hemispherical candle-power. The following table gives the distribution of light in a vertical plane:

Single Burner High Pressure Inverted Gas Lamp. English Type

Distribution of Light in a Vertical Plane

Angle Below Horizontal	Candle-power	Angle	Candle-power
Horizontal	1690	50°	1570
5°	1640	55	1330
10	1570	60	1300
15	1570	65	1290
20	1550	75	1180
25	1520	80	1090
30	1520	85	1000
35	1520	Vertical	960
40	1480		
45	1440		

Mean lower hemispherical candle-power........	1495
Gas consumption	31.6 cu. ft.
Candle-power per foot, M. L. H. S. C. P.........	47.3 c. p.
At 20° angle	49.0 c. p.

German Type. The prevailing German type contains three mantles with a consumption of about 65 to 70 feet per hour, and a rating of about 3500 mean lower hemispherical candle-power. The following table shows the distribution of light in a vertical plane:

Three Burner Press Gas Lamps

Angle Below Horizontal.	Indoor Test.
0°	3520 c. p.
10	3780 c. p.
15	3930 c. p.
20	3880 c. p.
30	4070 c. p.
40	4050 c. p.
50	3740 c. p.
60	3800 c. p.
70	2870 c. p.
80	2240 c. p.
90	2320 c. p.
M. L. H. S. C. P.	3520 c. p.
Gas consumption per hour	70.3 ft.
Candle-power per foot, M. L. H. S. C. P.	50.1 c. p.
At 20° angle	52.2 c. p.

Pressure 72.1 inches of water.

See Fig. 18.

Cost of Operation. While the conditions in Europe affecting the costs of operation would be entirely different from those in this country, the figures may be adjusted on the basis of American conditions.

The latest available statistics of the German system show that the mantles of the large lamps last 11.3 days and the globes 223 days. One workman can care for about 50 lamps. It takes about 1 horse-power, or 20 feet of gas used in a gas engine, for about 1400 cubic feet of press gas. The lamps consume about 65 feet of gas per hour. The actual costs in Berlin are stated to be as follows:

Operating Costs of High-Pressure Inverted Gas Lamps

Compression Cost, 4.76c. per Thousand Feet, Including Depreciation and other Expenses

Compression cost per hour per lamp	.31c.
Maintenance, mantle renewals, etc	.58c.
Total maintenance and compression expenses	.89c.

Gas, which is figured at 61 cents per 1000 feet, costs 3.98 cents. Total cost per hour per lamp, 4.87 cents. For 3675 hours, the burning time in Berlin, the total cost is $178.97. This is, of course, without allowing for the expense of the separate mains.

Introduction into this Country. At the present time there are only two or three experimental installations of high-pressure gas in the United States. There is one very satisfactory demonstration being made immediately outside of the building occupied by the United Gas Improvement Company in Philadelphia. There is another installation in a square in Brookline, just outside of Boston. (See accompanying photographs, Figs. 19 and 20.) Other installations have been made in Chicago and Milwaukee, and some other cities.

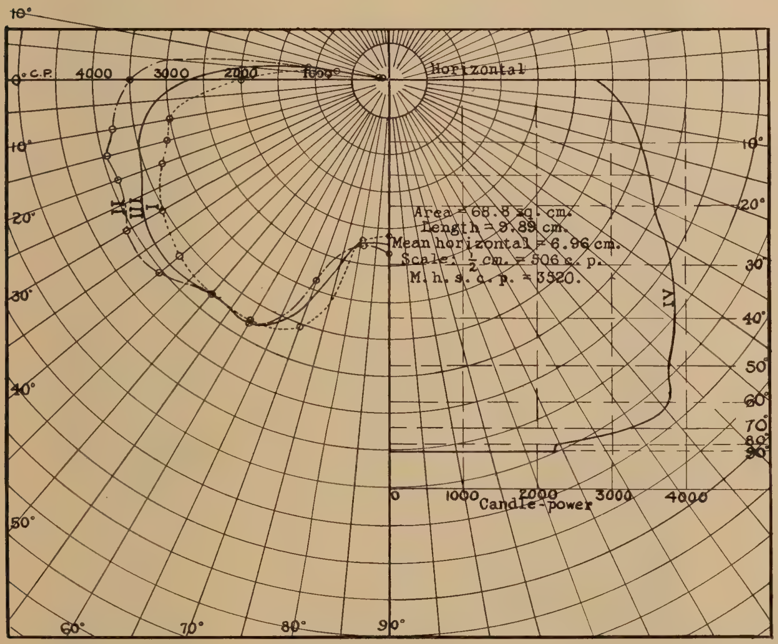


FIG. 18.

THREE MANTLE PRESSURE GRAETZIN LAMP.
(In Photometer Room.)

I. Curve showing the distribution of light in the vertical plane of two mantles.

II. Curve showing the distribution of light in the vertical plane perpendicular to the plane of two mantles.

III. Curve showing the mean of I and II.

IV. Rousseau diagram showing the mean hemispherical candle-power based on Curve III.

It is probable that the smaller unit consuming about 25 feet of gas and giving about 1500 candle-power is best adapted for American conditions. There would seldom be the necessity, except in some cases of spectacular lighting, or in the illumination of large squares, where the larger lamps would be required. With this lamp the cost can undoubtedly be brought within the limits prescribed by American municipalities.

FIG. 19.—High Pressure Gas Lamp.

The installation and expense of special mains and compressing stations will necessarily offer some difficulty in connection with the extension of high-pressure gas street lighting in this country. For existing business now undertaken with gas, it may not be found profitable to introduce high pressure, but in going into new fields now occupied by electric arcs the investment would probably be justified.

FIG. 20.—High Pressure Gas Lamps at Night.

Much more experimental work must be carried on in adapting the foreign lamps to our American conditions and in determining the costs of operation in this country. We shall expect, however, that in a short time the present examples will be supplemented by other installations.

VI. Automatic Lighting and Extinguishing of Gas Street Lamps

Types in Use. Automatic lighting and extinguishing of gas lamps may, at the present time, be divided into two distinct types. In one case lamps are automatically lighted and extinguished by the operation of clock movements contained in the lamps. In the other, the operation is performed by pressure waves sent out from the distribution stations.

Clock Lighter. One type of clock system has a heavy tinned body, which contains the controlling clock movement. From the top of this case extends the tube supplying the gas burner. The burner tube contains a long rod, which extends to the top inner part of the casing and is in connection with the trip springs. There is a small diaphragm in the lower part of the burner at the top end of this rod, preventing any gas leaking back. This rod works the main and pilot lights. The pilot is a non-luminous flame and is situated inside of the mantle. Therefore, it is protected from the weather and does not carbonize. It is extinguished when the main burner is lighted.

There is a disc which revolves on the main clock shaft once in 24 hours. There are two changeable lugs that turn in slots for setting at the required lighting and extinguishing times. The clock is wound from the back side, the lugs set and disc revolved to the correct time of day. As the lighting time approaches, the lugs engage a spring trip connected to the gas rod, which opens the gas valve instantly, thus letting the full volume of gas enter the burner, which is thereupon lighted from the pilot flame. The lamp is extinguished in a similar manner by closing the main gas valve.

Pressure Lighters. One type of pressure apparatus is designed as follows: It has a heavy tin body, diaphragm for operating clock work, diaphragm for operating pilot and main gas valves, small pan for holding shot and clock work. This type has three impulses, arranged so that all lamps light on the first impulse, some stay lighted on the second impulse, while others go out. The rest go out on the third impulse.

The main diaphragm is in a horizontal position. Under normal conditions, say 3-inch pressure, there is a pan containing just enough shot to balance a piston on the diaphragm. This clock work consists of a large spring, some governor wheels and pinions. The gas-controlling wheel has two functions. On one side of the spindle is a solid disc with three sets of slots, and on the other end is a star wheel. This wheel controls the plunger that opens and closes the gas valves, and the V-shaped toothed wheel controls the clock work. As the excess pressure is brought to bear on the diaphragm it overcomes the weight in the pan and presses the diaphragm plunger up until it strikes the clock-work lever. This releases a brake which fits into the V slots and starts the clock work, as well as the star wheel which is connected to the same spindle. As the plunger strikes the top of the star wheel it opens the main gas duct and closes the pilot tube. As the whole body is by-passed by the gas supply, there is no gas nor moisture whatever coming in contact with the working parts. By a similar operation the main gas supply is closed and the lamp is extinguished.

Present Examples. While there are several isolated examples of the automatic lighting and extinguishing of gas street lamps in this country, we must look to European cities for more extended experience.

Such examples may be found in Tottenham, England, where there have been some 1400 lamps of the upright type actuated by pressure from the works. Stuttgart has about 4000 of the pressure type.

In Bournemouth, England, there are about 1300 lamps of practically the same type. In Coblentz there are about 1500, and in Koenigsburg about 1500 also of the pressure type. In Liverpool the clock system has been in use.

Opinion is divided among the merits of the various systems, but the evidence is to the effect that the installations have been quite satisfactory.

The pressure wave required is only an inch or two, and is put on and released gradually, occupying an interval of only about 5 minutes.

The clock systems have the disadvantage of requiring periodical winding, but may be more certain in action. The fact that the whole territory has not been covered in some of the foreign cities

leads to the suspicion that only the most favorable part of the city has been selected.

Experiments are being conducted in Boston on a small scale, but it is too early to publish any reliable data, or to express an opinion. Questions of interference with the commercial system, of the accidental extinguishing of pilot lights, and of the pressure wave being dissipated on account of the commercial consumption,

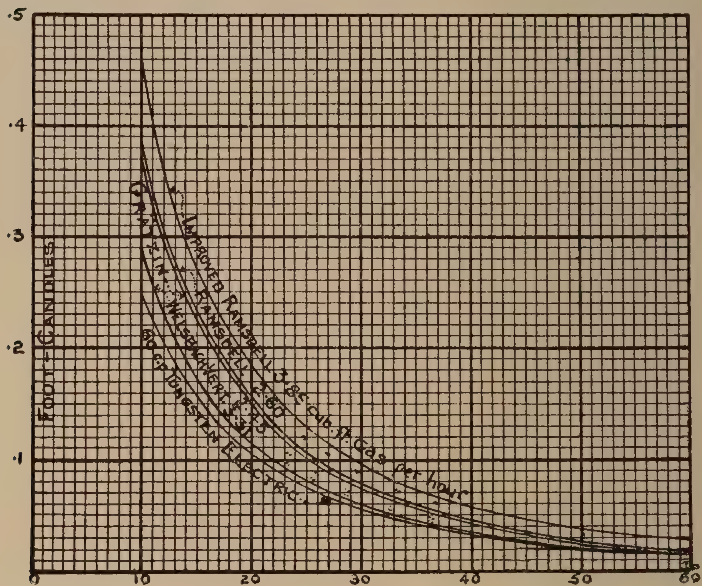


FIG. 21.
CITY OF BOSTON.
Street Department—Lamp Division.
Tests of Street Lamps.

Illumination on a plane at right angles to the light-ray, and 4 feet above the ground.

Summary of 735 observations, Nov. 30, 1909, to Feb., 1910.

Grätzin	Inverted Mantles..	3 series on 19 lamps.
Ramsdell	Inverted Mantles..	3 series on 18 lamps.
Improved Ramsdell	Inverted Mantles..	3 series on 2 lamps.
Welsbach Vertical		3 series on 15 lamps.
Tungsten 60 c. p. Electric..............		1 series on 9 lamps.

1 foot-candle = illumination on a surface 1 foot distant from a light of 1 candle-power.

1 candle-power = light produced by a standard spermaceti candle, ⅞-inch diameter, weighing ⅙ pound burning at the rate of 120 grains per hour.

Gas burners maintained in good condition—gas consumption at normal pressure of 2.8 inches water.

Electric bulbs in continuous use since Sept. 3, 1909.

especially in the winter time, will all have to be determined. Considerable hope, however, is entertained of the possibilities of this system, especially for use where the cost of labor is high. It must be remembered that in any automatic system a certain amount of labor will in any event be required for inspection, cleaning and adjusting.

Fig. 22.—Gas Lamps Taken on Marlboro Street.

VII. Miscellaneous

Maintenance of Candle-Power Efficiencies. While conditions of the tests shown above in the photometer room were more favorable than in the case of lamps burning out-of-doors, it will be noticed that in some cases the outdoor tests gave higher candle-power results than the indoor tests.

Comparison has sometimes been made to the disadvantage of gas lighting by measurements taken of gas lamps in poor condition, or in old-style burners. While the outdoor tests mentioned were made under good conditions, we would not expect any great depreciation in candle-power for the lamps if given satisfactory care and periodical inspection during their operation.

The accompanying data secured from the former Superintendent of Streets of the City of Boston gives the average results of 735 observations from November 30, 1909, to February 3, 1910, of lamps in actual service on the streets of that city. In determining the rate of consumption, the whole number of lamps was not tested, but several average lamps were tested, and the result applied to the

FIG. 23.—Electric Lamps Taken on Marlboro Street.

whole number. The comparative consumptions indicated are, therefore, not necessarily conclusive as the conditions of pressure and adjustment may not necessarily have been the same as when the lamps were in use on the streets. (See Fig. 21.)

Physiological Advantages. A comparison of the value for street lighting of incandescent gas and electric lamps cannot fairly be based on the actual candle-power developed. It is one of the curious phenomena of physiology that at comparatively low intensities, the eye is more sensitive to a white light or to a light with a tinge of green or blue than to a yellow, orange or reddish light.

Accordingly, of two streets lighted by gas and electric lamps of equal candle-power, spaced the same distance apart and hung at

the same height, that lighted by the gas-mantle system will have the more effective illumination, although the actual foot-candles in the two cases may be the same. This physiological fact (known as the Purkinje effect) is reversed at high intensities, yellow light having more effect on the eye than the light tending more to the blue end of the spectrum.

It follows that with a street lighted by yellow lights the spotty effect will be accentuated, for the high illumination directly under

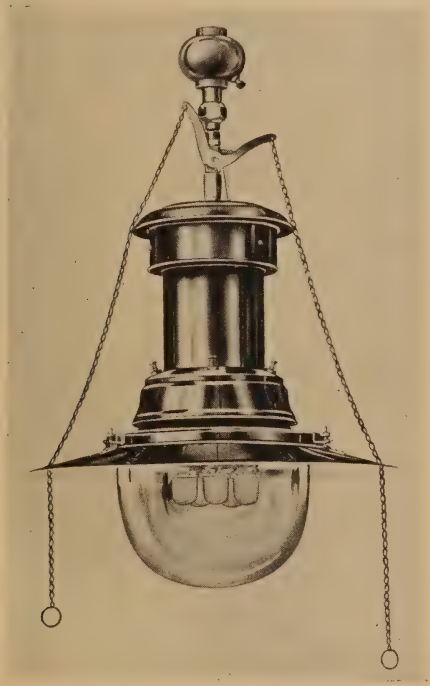
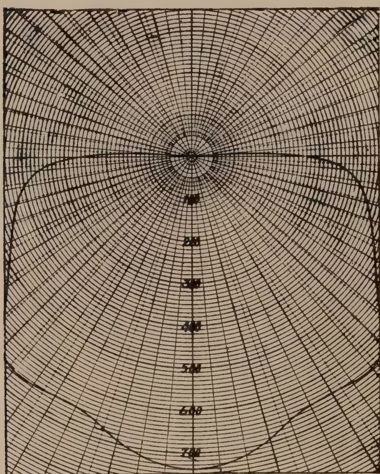


FIG. 24.—Outdoor Gas Arc.

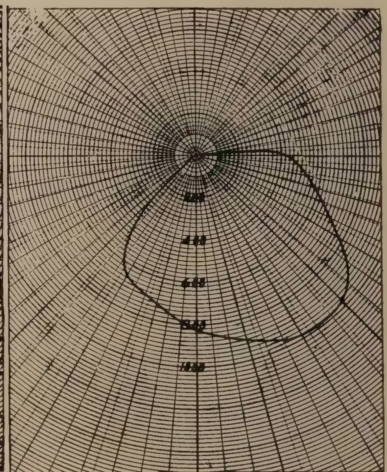
the lamp will have strong effect on the eye, whereas the low illumination between lamps will react on the retina only faintly. With lights which have a greater proportion of rays in the blue end of the spectrum, the opposite and desired result is reached. An example of such a comparison is shown in the photographs (Figs. 22 and 23) exhibited herewith. Fig. 23 is the electrically lighted portion of the street. Fig. 22 is the gas-lighted portion.

The candle-power values of the electric and gas lamps on the

street are almost the same. The height of the lamps and the spacing are also practically identical, and yet the photographs taken under the same conditions of exposure and printing, and re-



Outdoor Gas Arc.



Arc with Angle Reflector.

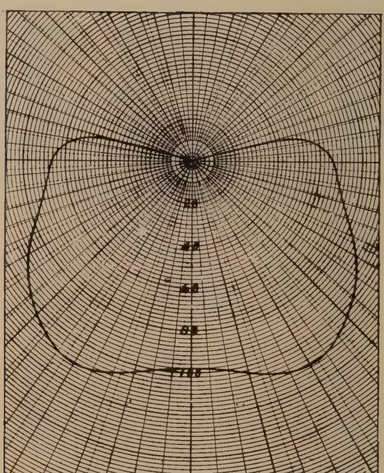


FIG. 25.—Portico Light.

produced without retouching, verify what to the eye is readily apparent, namely, that the illumination in that portion of the street lighted by the gas lamps is superior to that in the section lighted by the electric lamps.

DIVISION B—OTHER OUTDOOR LIGHTING

Arc Lights. The ordinary types used indoors, both upright and inverted, are adapted for outdoor use in the lighting of the exterior of stores and similar buildings. A heavier material is used for the outside casing, and the lamp is made rain- and wind-proof as far as possible. In some cases the same type of inverted lamp which is used for street lighting is also used for the outdoor commercial lighting. Some very striking installations are found, the

FIG. 26.—Portico Light.

lamps being used for display and spectacular lighting, principally for advertising purposes. Some adaptations are designed with an angle reflector to concentrate the rays upon the windows or some other objects.

Portico Lights. The single inverted burner has also been applied for the lighting of porches, and has lately received considerable development. (See Figs. 24 and 26.)

DIVISION C—CONCLUSION

It has been shown from the above tests that the efficiency of the upright gas lamp is about 20 mean lower hemispherical candle-power per cubic foot. That of the single inverted gas burner is about 30 mean lower hemispherical candle-power per cubic foot, and that of the two-mantle inverted lamp is about 35 mean lower hemispherical candle-power per cubic foot.

The efficiency of the high-pressure inverted lamps is about 50 mean lower hemispherical candle-power per cubic foot.

From the types mentioned selection can easily be made to suit the required conditions. With gas at low pressure there is the upright boulevard lamp, containing one or two burners and rating from 60 candle-power to 120 candle-power. The curve of distribution of this lamp is especially well adapted for street lighting.

The foreign inverted lamps under low pressure are somewhat more efficient but require special posts with extended arms. The distribution curve is not so effective unless the lamp is suspended somewhat higher from the street level than the upright lamp. The candle-powers rate at from 100 to 200 with one or two burners.

With high-pressure gas we can obtain 500 candle-power, 1000 candle-power, 1500 candle-power, 3000 candle-power, and up to 4000 candle-power, the field for the large light source being fully covered. These high-pressure lamps may be upright or inverted, but preference is now given to the inverted type.

On account of the low intrinsic brilliancy and the comparatively large area of the light source, the effect produced by gas lamps is very satisfactory, the light being soft and well diffused without glare.

Exterior lighting by gas will, consequently, continue to increase in popularity and will cover an ever-widening field.

In conclusion, I desire to express my appreciation of the assistance furnished me in the preparation of this lecture by Professor Drehschmidt, of Berlin; Professor D. C. Jackson, of the Massachusetts Institute of Technology; Guy C. Emerson, former Superintendent of Streets of the City of Boston, and F. V. Westermaier, of the Welsbach Street Lighting Company, Philadelphia.

XV

SHADES, REFLECTORS AND DIFFUSING MEDIA

By Van Rensselaer Lansingh

CONTENTS

This paper does not take up the subject of windows for day lighting or diffusing media, such as coverings for walls, ceilings, etc., but deals only with shades, reflectors, refractors and diffusing media for artificial light.

A shade may be defined as an article whose principal function is to soften or diffuse the light, or else produce a given artistic effect. A reflector, on the other hand, is an article whose primary function is the redirecting of the rays of light by either regular or diffuse reflection. When light is transmitted through glass, but its direction is changed by means of prisms, we can term such an article a refractor.

Shades, reflectors and refractors can be classified as given on p. 887.

Decorative Shades—Div. A

Clear Glass, Div. A, Class 1. Clear glass is used, as a general thing, only as a protective covering, no attempt being made to either diffuse or direct the light. In the case, however, of clear-glass shades with open mouths, considerable reflection is obtained from the inside surface of the glass, as is shown by the multiple images of the filament of an incandescent lamp when placed inside. This same phenomena of surface reflection is present in all shades or reflectors having polished interior surfaces, whether they be opal, prismatic or otherwise, but it is generally less marked than in the clear-glass shade. In the former, the primary reflection, such as that of the prisms of a prismatic reflector, overpowers the lesser surface reflection, so that the streaks due to surface reflection are less pronounced. The absorption of clear glass is, generally speaking, in the neighborhood of 10 per cent.

Cut Glass, Div. A, Class 2. Such glass, either genuine or simply pressed to look like it, does not, as a rule, present as good an appearance when viewed by transmitted light as when seen by reflected light. Shades, therefore, of this order are not, as a rule, satisfactory, except in certain special instances. In addition to this, on account of the broad facets, there is apt to be a dazzling brilliancy which is tiring to the eye. The absorption is likely to run high, seldom, if ever, falling below 20 per cent.

Fig. 1 shows a clear, pressed-glass stalactite, while Fig. 2 shows its photometric curve. Such a globe gives poor diffusion, with an absorption of about 25 per cent. At the same time the general shape of the photometric curve of the bare lamp has not been

CLASSIFICATION.

DIVISION A—

Decorative.....
- Clear glass, Class 1
- Cut " " 2
- Bead " " 3
- Ground " " 4
- White " " 5
- Tinted " " 6
- Art " " 7
- Fabrics
  - Cloth, Class 8
  - Paper, " 9

DIVISION B—

Diffusing.......
- Ground glass, Class 1
- White " " 2
- Colored " " 3
- Prismatic " " 4
- Fabrics " 5

DIVISION C—

Directing.......

(Reflectors Refractors)
- Diffuse reflection
  - Opaque.....
    - Symmetrical / Assymmetrical — Interior surface
      - White.........
        - Enameled porcelain, Class 1
        - " paper, " 2
        - Asbestos, " 3
        - Paint, " 4
      - Aluminum....
        - Paint, " 5
        - Matt metal, " 6
      - Miscellaneous
        - Copper / Brass / Tin — shades rather than reflectors, Class 7
        - Fluorescent salts, " 8
  - Translucent
    - Symmetrical / Assymmetrical — Interior surface
      - Fabrics, Class 9
      - Glass / Porcelain
        - Ground or etched glasses, Class 10
        - Opal and white glasses, " 11
- Regular reflection or refraction
  - Opaque.....
    - Symmetrical / Assymmetrical — Reflection by
      - Polished metals
        - Aluminum / Silver / Tin / Zinc / Copper, etc. — Class 12
      - Mirrors.........
        - Plain mirror strips, Class 13
        - Corrugated mirror strips, " 14
        - Silvered reflectors, " 15
  - Translucent
    - Symmetrical / Assymmetrical — Prisms
      - Refractors, Class 16
      - Reflectors, " 17

materially changed. The use, therefore, of such shades is not desirable, and is growing rapidly less.

Bead Glass, Div. A, Class 3. Shades formed of bead glass are similar in their characteristics to cut glass, except that they are much more diffusing and, therefore, pleasing to the eye. This is

FIG. 1.—Pressed Glass Stalactite.

accomplished at a comparatively large absorption loss, varying from 40 to 60 per cent or more. The reason for this is at once evident if we consider that the face of each bead either reflects or refracts the light, and the chance of any special ray being transmitted rather than being thrown back again is not large, resulting, therefore, in a heavy absorption loss. Owing to the difficulty of cleaning such a shade, this loss is apt to be extremely high after the shade has been in service for some time.

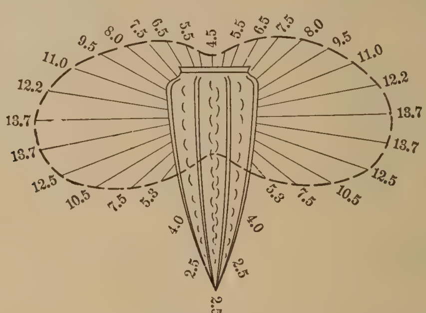


FIG. 2.—Photometric Curve of a Pressed Glass Stalactite.

Fig. 3 shows a beaded hemisphere and Fig. 4 its photometric curve with a 50-candle-power lamp. Inasmuch as hemispheres are generally used on ceilings, and the majority of the light is wanted

in a zone not greater than 60 degrees from the vertical, it is apparent that such lighting is extremely inefficient. A slight change, however, may considerably improve matters.

Fig. 5 shows the curve of the same bowl when the lamp is

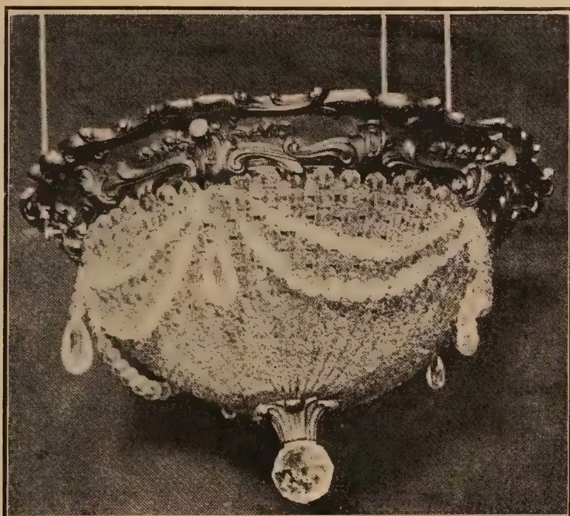


FIG. 3.—Beaded Bowl.

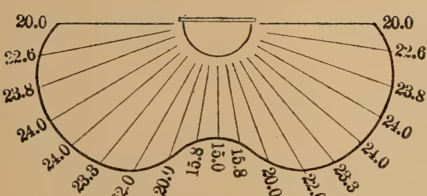


FIG. 4.

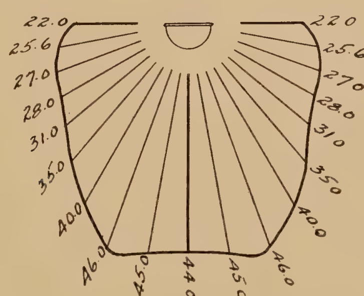


FIG. 5.

FIG. 4.—Light about a Beaded Bowl, 50 Candle-Power Lamp (no Reflector).

FIG. 5.—Light about a Beaded Bowl with a 50 Candle-Power Lamp and Prismatic Reflector.

equipped with a properly designed prismatic reflector. The increase in the flux below the horizontal is 34 per cent, and in the 60° zone no less than 60 per cent. It may be noted here that the

absorption of such shades will depend largely upon the closeness with which the beads are strung. If strung comparatively far apart the absorption will be considerably less, but, on the other hand, the diffusion and artistic effects are greatly diminished, as in such cases it is generally possible to see clearly the electric incandescent lamps which are used inside.

FIG. 6.—Roughed Inside Shade.

Ground Glass, Div. A, Class 4. Under this may be included all different forms of ground and etched glass, which are made in a great variety of patterns. Such shades, as a rule, are primarily intended for decorative effect, but also give considerable diffusion and, in certain cases, some redirection of light.

Fig. 6 illustrates a typical frosted or ground-glass shade.

FIG. 7.—Photometric Curve of Roughed Inside Glass Shade.

Fig. 7 shows its photometric curve. It will be noted that such shades tend to strengthen the end on candle-power at the expense of the horizontal. No particular distribution of light is obtained, however, and as such shades are more often used upright than pendant, they must be considered as principally decorative and diffusing, rather than redirecting. If roughed on the outside and smooth on the inside, a considerable difference in distribution occurs.

Fig. 8 shows a typical etched shade for open gas, and Fig. 9 its photometric curve. In this case, owing to the shade being etched on the outside, and the inside having the usual smooth surface, there is considerable specular surface reflection, resulting in a

FIG. 8.—Smooth Inside Etched Shade for Open Gas.

large upward flux. If the shade had been used pendant, a corresponding flux would have been thrown downward. This shade can be considered typical of shades of this class, etched on the outside and smooth on the inside.

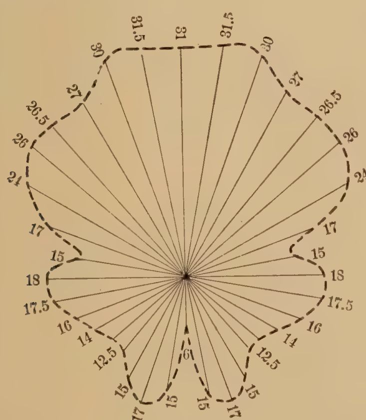


FIG. 9.—Photometric Curve of Etched Shade for Open Gas Flame.

Etched- or ground-glass shades have a fairly low absorption, running from 10 to 25 per cent, depending on, first, the flux which strikes the glass, and, second, on the density and quality of the roughening, as will be explained later.

White Glass, Div. A, Class 5. Under this is included all the different tints and shades of white or opal glassware. When not intended primarily for diffusion, white glass is, as a rule, decorated with patterns which can be made to give beautiful effects. When

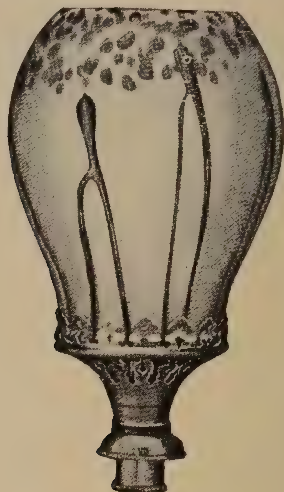


FIG. 10.—Fancy Opal Shade.

of the enclosing type, such as a ball, there is generally a considerable loss by absorption, varying from perhaps 15 per cent in certain instances up to 50 and 60 per cent when the shade is highly decorated.

FIG. 11.—Photometric Curve of Fancy Opal Shade.

Fig. 10 shows a typical fancy opal shade, and Fig. 11 its photometric curve. It will be noted that there is no marked change in the distribution of light, but only a large absorption. As an offset to this, there is practically perfect diffusion and a good appearance.

Tinted Glass, Div. A, Class 6. Under this heading can be considered all of the different forms, shapes and colors of colored glass, ranging from the most delicate tints to the deepest colors. The absorption of such shades is, as a rule, high, although not necessarily so, depending both upon the character of the glassware and the kind of radiator used. With ordinary modern light sources, a shade tinted yellow would have a comparatively low absorption when compared with one tinted blue, inasmuch as the yellow rays, with which the radiator is, as a rule, rich, will be transmitted in the yellow shade, but mostly absorbed in the blue shade. The absorption will, therefore, vary in such shades with the character of the radiator used. A shade may appear quite different when used with a tungsten-filament lamp as compared with a carbon-filament lamp, the latter emphasizing the colors at the lower end of the spectrum, while the former will bring out more clearly the colors at the upper end of the spectrum.

As a rule, such shades have little or no directing power, except from surface reflection, but if lined with white opal, as is done in certain instances, the beauty of the shade may be enhanced owing to the softening of the colors, and considerable reflection obtained from the white interior surface.

Art Glass, Div. A, Class 7. This is generally made up of small pieces, leaded to form a large shade, or it may consist of a single piece of glass decorated either with a pattern or with pictures, etc. Such shades, as a rule, serve only two functions, namely, to give a certain decorative effect and to soften the light which shines through. Beautiful effects can be obtained with such glass, but, of course, at a very high absorption loss, which may be as high as 90 per cent or more. Their directing power is, as a rule, nil.

Fabrics, Div. A, Classes 8 and 9. Fabrics are often used for decorative effects, and may consist of cloth or paper, or possibly other materials. Such shades are often lined with either white cloth or white paper, in which case they make fairly good reflectors, and at the same time may give beautiful effects due to transmitted light. If not so lined, their reflecting power is extremely low. The absorption in such cases varies the same as with tinted glass, and is, as a rule, lower with colors at the lower end of the spectrum than with colors at the upper end of the spectrum.

Diffusing Shades—Div. B

Up to the present time, there is no definite method of comparing the diffusion given by one glass with another. A method, however, has been suggested * by taking the ratio of the lightest and darkest points on the surface, in the case of transmitting glass, and the ratio between the direct and diffuse reflection of reflecting glass. This ratio would give a coefficient of diffusion which might be used to advantage in comparing—other than by the eye—the diffusion of the two different forms of glass. It is to be hoped that some such scheme will be adopted so that it will be possible to compare different forms of glass as regards this important quality.

Ground Glass, Div. B, Class 1. Under this heading is included clear glass, which has been made diffusing by either sand-blasting or acid etching the surface. Ordinarily, no distinction is drawn between these two methods of producing diffusion, yet, as a matter of fact, we have probably two different physical phenomena. In the case of glass roughened by sand-blasting,† we find if we use a powerful microscope that the surface of the glass looks as though it were covered with small scales of clear mica with extremely sharp and ragged edges. Such edges undoubtedly cause diffraction, while, of course, the smoother parts of the surface produce refraction, so that in the case of such glass we have both phenomena occurring. Inasmuch, however, as diffraction—which is a large factor in such glass—causes the rays of light to bend but a slight amount, the diffusion obtained from such glass is not as great as may be obtained by other means. In addition, in the case of sand-blasting where the surface is very rough, there is a good deal of internal reflection, resulting in a higher absorption loss. In the case, however, of acid etching, we find, on examination by a powerful microscope giving a magnification of several hundred diameters, that the surface has an entirely different appearance from sand-blasted glass, there being no sharp edges, but the surface is pitted between rounded projections, as though small worms were crawling over the surface of the glass. Under such circumstances, diffraction is probably absent, and the diffusion is obtained by refraction combined with some reflection. For this reason, equal diffusion is generally obtained at a slightly lower loss by absorption, inas-

* E. L. Elliott, "Illuminating Engineer," August, 1910, p. 307.

† "Illuminating Engineer," December, 1910, p. 526.

much as internal reflection is lessened as compared with sand-blasted glass. Such absorption losses may vary from as low as 5 per cent, in which case but little diffusion is obtained, to as high as 10 or 15 per cent, in which case good diffusion is obtained, these figures being the additional absorption over the clear glass, so that such a shade completely enclosing the lamp would have an absorption varying from 15 to 25 per cent.

White Glass, Div. B, Class 2. In the case of diffusion obtained by white or opal glass, we have still a third method—namely, diffusion by total reflection as well as some refraction. Opal glass almost always consists of a clear "body," in which are imbedded

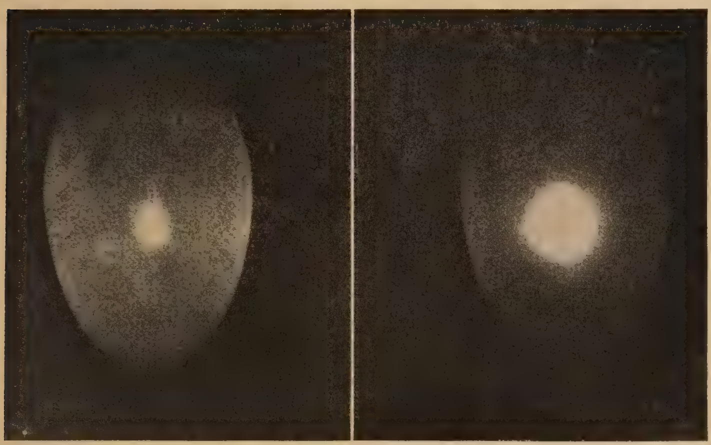


FIG. 12.—Showing Diffusion of Opal (Left) and Ground-Glass (Right) Globes.

minute opal particles, which may be large enough to be visible, or else of extreme minute dimensions, approaching in some cases molecular size. If a piece of opal glassware, such as is ordinarily used, is examined under a powerful microscope and a strong beam of light is transmitted through it, one immediately is fascinated by the sight of these minute particles reflecting light to the eye from all directions. Inasmuch as such particles lie at all possible angles, one would naturally expect the light to be reflected in all directions, and if the density of the opal is great enough, we find this actually takes place, and practically perfect diffusion is obtained, each point of the shade being a secondary source of light.

Fig. 12 * shows the diffusion actually obtained with an opal globe on the left and a sand-blasted globe on the right, with a 2-candle-power lamp with an exposure of 15 seconds.

The result of the diffusion obtained in any of the above three mentioned ways has the natural result of rounding out the photometric curves, and a distribution more nearly spherical will be the resultant photometric curve.

Fig. 13 shows a change in the distribution of light due to enclosing an ordinary 16-candle-power carbon-filament lamp with a ground-glass globe. It will be noted that the places where the light was weakest—namely, at the nadir and zenith—have been increased in candle-power, while on the horizontal, where the candle-power is greatest, we have a reduction.

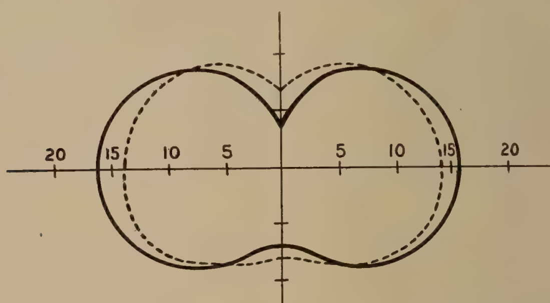


FIG. 13.—Showing Change in Distribution of Light Due to Diffusing Globes.

We have already seen the nature of the diffusion obtained by white glass. The absorption will vary through a wide range, depending upon both the density of the glass and also the color of the opal used. Many of the lighter opals, which run to a yellowish tinge, are called "opaline," but these can really be considered under the head of tinted glass. The white glasses *may* have an extremely low absorption factor—perhaps not over 15 per cent in the case of certain types which give fairly good diffusion. At the same time a somewhat similar shade giving perhaps but little better diffusion may have an absorption loss as high as 50 or 60 per cent. The question, therefore, of selecting a proper white diffusion shade, in which the primary idea is diffusion rather than

* Frontispiece to "Radiation, Light and Illumination," by C. P. Steinmetz. See also page 222 of same book.

redirection, is to get one in which the diffusion is obtained at a comparatively low absorption loss. Naturally, such results cannot be obtained by inspection, and in the case of large installations such shades should be bought on a specified guarantee, which should be proved by photometric tests. In such specifications, the kind of lamp, the position and candle-power should all be specified. Inasmuch as it is now possible to obtain white glasses on the market with low absorption factors, there is little or no excuse for using opal glassware through which the filament of the lamp is plainly visible, and it is to be hoped that this type of glassware will be gradually eliminated.

Colored Glass, Div. B, Class 3. This subject has been covered in considering tinted glass, under the general title of "Decorative Shades," and need not be taken up further.

Prismatic Glass, Div. B, Class 4. Diffusion may be obtained by means of prisms used on both the inside and outside of a body of clear glass. These prisms may be simply ridges cut in the glass, in which case the diffusion is apt to be streaked and a double image of the lamp filament can be plainly discerned, or they may be scientifically designed to give practically perfect diffusion, and at the same time direct the rays of light in given definite directions. This latter glass will be considered under the head of refractors. The absorption of such shades varies in quite a remarkable manner. The mean of a number of carefully made tests on carefully designed closed types of such globes showed an average of only 12.4 per cent, whereas, on similar shaped globes, but with uncalculated prisms, the absorption ran as high as 32 per cent.* The reason for this is evident if we consider that when a ray of light strikes a prism which has not been definitely placed in the correct position, the ray of light is apt to be turned back into the globe again. The phenomenon is exactly similar to that mentioned in the case of beaded glass, taken up in the first section of this paper, where very high absorptions are obtained. The diffusion obtained from such glass, however, even in the case of that which is well designed, is not absolutely perfect, the surface of the globe being dotted with small spots of light. Viewed from a distance of a few feet, however, the globe looks practically uniformly lighted, although the diffusion obtained is not as good as that from a dense opal.

* Technology Quarterly, 1902.

Fabrics. This subject has already been covered under the head of "Fabrics," in the section of "Decorative Shades," and need not be taken up further here.

Directing Materials—Div. C

Under this head will be considered both reflectors and refractors; a reflector being an article whose primary function is to reflect the light either by specular or diffuse reflection; whereas, a refractor is one in which the light is transmitted but turned out of its course, generally by means of prisms.

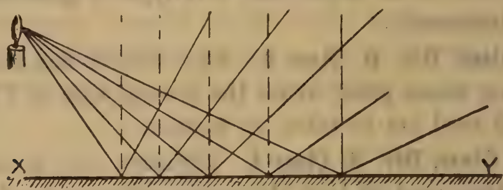


FIG. 14.—Regular Reflection.

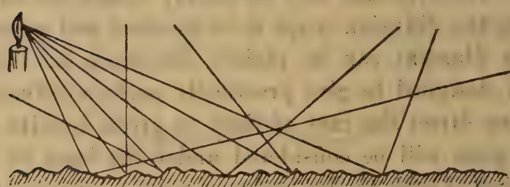


FIG. 15.—Irregular Reflection.

Reflecting properties are generally classified as either regular or specular reflection on the one hand, and irregular or diffuse reflection on the other.

Fig. 14 shows an example of regular reflection where each ray of light is reflected, so that the angle of incidence is equal to the angle of reflection. Fig. 15 shows an example of irregular reflection in which each ray of light is regularly reflected from the tiny area on which it is incident, but owing to the rough nature of the surface, the individual light rays are thrown in all directions. Ordinarily no distinction is drawn between irregular and diffuse reflection. A difference may, however, exist, as diffuse reflection may be due, not to a roughened surface, as in the diagram shown above, but to the nature of the surface or material composing the reflecting surface. Thus depolished opal reflects irregularly, due both to its roughened surface and also the opal particles composing the opal.

As shown in the classification, we first deal with reflectors acting by diffuse reflection.

Enameled Porcelain Reflectors, Div. C, Class 1. Enameled porcelain reflectors are used considerably in industrial work, and are especially advantageous in places where water or damp atmosphere is liable to affect other surfaces, and where conditions are such as to make it difficult to keep other reflectors clean. Such reflectors act generally by diffuse reflection, although there is a certain amount of surface reflection as noted in Div. A, Class 1. Usually such reflectors are made in a plain cone and give only one

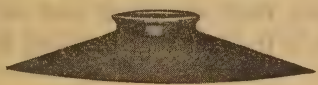


FIG. 16.—Typical Enameled Reflector.

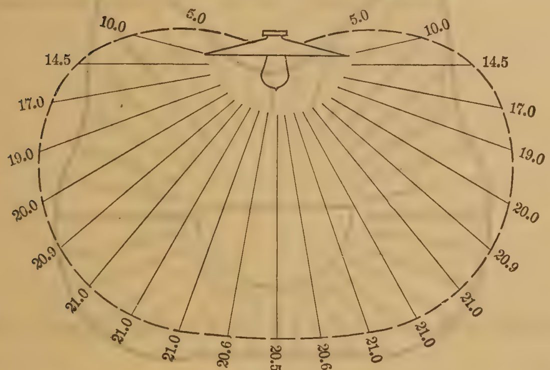


FIG. 17.—Photometric Curve of Enameled Reflector.

type of distribution. Lately, however, reflectors of this type have been placed on the market to give different distributions, although the possible variation is not great, owing to the fact that these reflectors act mostly by diffuse reflection.* Owing to cross-reflection, which of necessity takes place largely in diffusing reflectors, the efficiency of such is not as high as those which act more by specular reflection, such as those considered in Div. C, Classes 5 and 6.

Fig. 16 shows a typical enameled reflector and Fig. 17 its photometric curve.

* See "Transactions" Illuminating Engineering Society, January, 1910, p. 49.

Enameled Paper Reflectors, Div. C, Class 2. These act but little differently from those considered under the last heading, but, owing to their fragility, their liability to catch dust and dirt, and the fact that they cannot be cleaned, renders them of but little practical value for commercial work. With a high surface gloss, there is more or less specular reflection, but, generally speaking, their action is similar to those considered in Div C, Class 1.

Asbestos Reflectors, Div. C, Class 3. As is well known, a white mat surface, such as asbestos, is a good reflector, and if cross-reflection is avoided asbestos reflectors compare favorably with other reflectors, when they are clean and in perfect condition. A further advantage is the fact that they can be used where paper

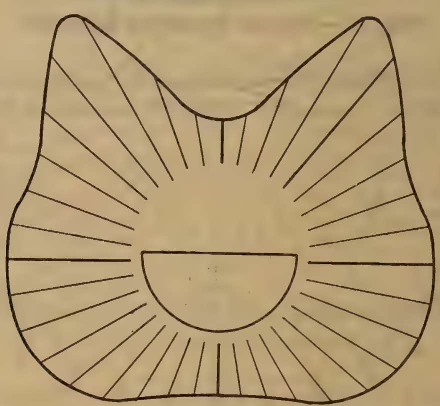


FIG. 18.—Characteristic Curve of Sand-Blasted Hemisphere.

reflectors would be inadvisable on account of the heat. As a rule, it is difficult to renew the surface of an asbestos reflector, except by scraping, but if there is sufficient body, a new diffusing surface can be easily obtained in this manner. Such reflectors have not come into wide use, but in certain cases they play an important part. If made up in the ordinary reflector type, say a cone shape, they would probably be inferior to a good enamel porcelain, but if their interior surface is painted with proper aluminum paint, as is sometimes done, a good degree of efficiency can be obtained, the efficiency depending largely upon the smoothness of the surface. Another use of asbestos reflectors is in conjunction with hemisphere lighting. Ordinarily hemispheres are mounted on ceilings,

being held in position by a simple brass band. Generally, no attention is paid to directing the light downward. If a ground-glass bowl is used, a distribution such as shown in Fig. 18 results, where the majority of the light is thrown upwards and mostly lost.

If now a white asbestos reflector be employed correctly * a large increase in downward flux results, as is shown in Fig. 19.

It should be carefully noted, however, that the efficiency of the results will depend almost entirely on the correct mounting of lamp and reflector.

White Paint Reflectors, Div. C, Class 4. White paint is a much poorer reflector than a good enamel porcelain; furthermore, it is apt to chip off; as a rule it turns yellow with age and heat, and is practically never used except in the cheapest type of tin reflectors. There is so little to recommend it, excepting its low cost, that further consideration need not be given it here.

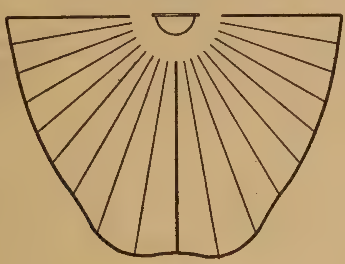


FIG. 19.—Characteristic Curve of Ground-Glass Hemisphere with Asbestos Reflector.

Aluminum Reflectors, Div. C, Classes 5 and 6. Such reflectors can either have a painted aluminum surface, or, if the reflector itself is made of aluminum, the surface may be matted or roughened Almost all of the reflectors considered heretofore could be and are, with the exception of Class 1, made with a painted aluminum interior surface, resulting, generally speaking, in an increase in efficiency, because aluminum is a good reflector. As a matter of fact, while aluminum reflectors are here classified under diffuse reflection, they really act more by regular than diffuse reflection, and, strictly speaking, should be so classified. This will be seen from the following two figures.

* "Practical Illumination," by Cravath & Lansingh, pp. 107, 114.

Fig. 20 shows the photometric curve of a 10″ aluminum painted steel plate with a comparatively rough surface. Fig. 21 is the same plate with a smoother surface. The plate was illuminated by a special 80-candle-power tungsten-filament lamp, having a very small filament, covered by a concentrating reflector giving parallel rays. In the tests shown, the angle of the incident rays was 50° from the normal, and, as will be noted, the majority of the light

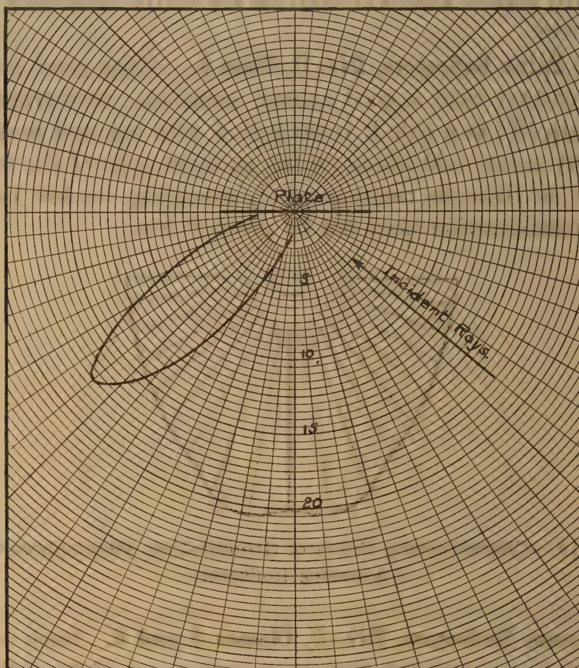


Fig. 20.—Light Reflected from Rough Aluminum Finished Plate.

was regularly reflected, there being but a comparatively small amount of diffuse reflection. It will also be noted that with a smooth surface there is a decided increase in the regular reflection; in this case an increase from 17.5 candle-power to 27 candle-power. Inasmuch as such reflectors, therefore, act largely by regular reflection, it is possible to vary their photometric curves through a wide range.

Figs. 22, 23 and 24 show typical photometric curves which can be obtained with reflectors of this type.

The question of deterioration is an important item in reflectors of this class. Deterioration may be due to two things—either a wearing off of the aluminum reflecting surface or the imbedding of small dust particles in the pores of the metal. Careful tests have been made on this subject and the results are interesting. If the aluminum is properly made and applied—and much depends upon this—the deterioration due to rubbing off of the aluminum

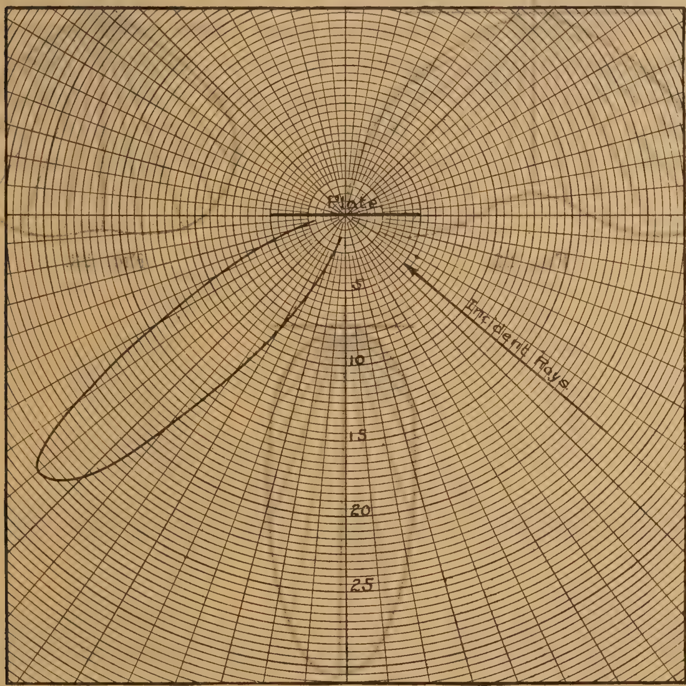


FIG. 21.—Light Reflected from Smooth Aluminum Finished Plate.

itself, even when scrubbed with soap and water, is practically nil. The depreciation due to imbedded dust particles will depend largely upon the character of the metal on which the aluminum is placed. If this is rough and porous, the permanent depreciation may easily run to 10 per cent or more; whereas, if the metal selected is fairly smooth and with closed pores, such depreciation will probably be only 3 or 4 per cent. It is, therefore, of importance to bear the above facts carefully in mind when selecting reflectors of this type.

Matt Aluminum Reflectors, Div. C, Class 6. This class differs in no way materially from Class 5, except that, generally speaking, such reflectors are not strong enough mechanically to withstand hard usage in industrial lighting. They are apt to be bent easily, because of the very soft metal of which they are made. With the exception of their fragility, however, these reflectors have all the characteristics of Class 5, with the added advantage that, as a

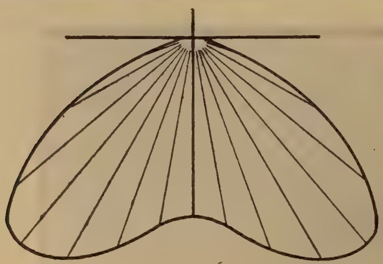


FIG. 22.

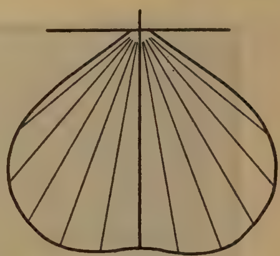


FIG. 23.

FIG. 24.

FIG. 22.—Aluminum Finished Reflector, Extensive Type.
FIG. 23.—Aluminum Finished Reflector, Intensive Type.
FIG. 24.—Aluminum Finished Reflector, Focusing Type.

rule, the surface of the reflector is smoother than in the case of those in which the body of the reflector is steel. Consequently, a somewhat more specular reflection is obtained.

Miscellaneous Diffuse Opaque Reflectors, Div. C, Class 7. These are sometimes made of copper, brass, tin or other metals, and if unpolished are really shades rather than reflectors, their principal

function being to hide the light from the eye. Their reflecting power is generally low unless polished, and they play but a very small part in ordinary lighting. When, however, they are polished they may give considerable reflection, and will be considered under Class 12.

Fluorescent Salts, Div. C, Class 8. Under this head we have to consider reflectors coated with fluorescent salts. The primary function of such reflectors is to change the wave length of the light rays which strike them, obtaining thereby a different color of light. Thus, in the case of the mercury vapor lamp, reflectors have been made of white enamel covered with certain fluorescent salts. When the rays of the mercury vapor arc strike such a reflector a large part of the rays are absorbed, the energy of the same

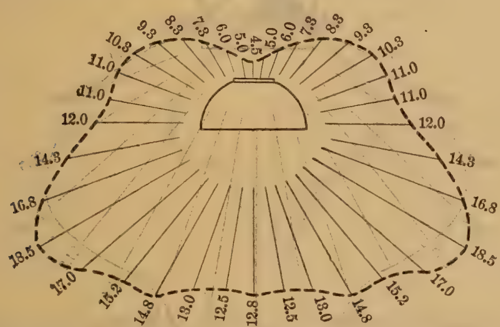


FIG. 25.—Photometric Curve of 16 Candle-Power Lamp and Ground-Glass Reflector.

being transmitted to the salts, which in turn fluoresce, giving out longer wave lengths, resulting in a mixture of red rays with the characteristic bluish-green color of the mercury vapor arc itself. Such reflectors, while of great promise, have not yet been introduced commercially, and as yet little is known as to their real value.

Translucent Diffuse Reflectors

Fabrics, Div. C, Class 9. A white fabric, when made of cloth or paper, is, as a rule, a good reflector. The amount of reflection, of course, will depend not only on the nature of the material but also the weave; a closely woven fabric being superior in its reflecting power to one which is loosely woven. Silk or linen is often used for lining the interior of ornamental domes made of fabrics, and

when so used materially increases the useful flux of light below, while at the same time it allows enough light to escape through the upper fabric to give the artistic effects desired. Thin paper sometimes is used on small portables, and gives good results. As a rule, such reflectors are not high in efficiency, and their principal use is for decorative effects.

Ground or Etched Glass, Div. C, Class 10. These are seldom good reflectors, although they may reflect some light.

Fig. 25 shows the distribution of light from a 16-candle-power lamp with a sand-blasted dome.

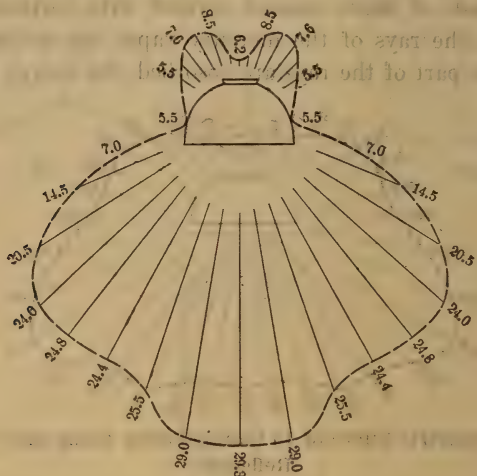


FIG. 26.—Photometric Curve of 16 Candle-Power Lamp and Opal Glass Reflector.

Fig. 26 shows the distribution of light from a similarly shaped opal reflector.

It will be noted that the reflecting power of ground glass is low. Such glass, however, is seldom used primarily as a reflector, but more for decorative or diffusing effects.

Opal and White Glass, Div. C, Class 11. This constitutes one of the most important classes of reflectors in ordinary use. The interior surface of such reflectors, if left with its natural glaze, gives considerable specular reflection, as is noted under Div. A, Class 1.

Fig. 27 shows a typical photometric curve of an opal cone reflector, the full line representing the reflector with its regular pol-

ished or glazed surface, and the dotted line the same after the glaze had been removed by acid etching.

With diffuse reflection, such as we get with depolished opal reflectors, it is not possible to vary the distribution curve through a wide range by varying the shape of the reflector.

Fig. 28 shows six different shaped depolished opal reflectors and their photometric curves, illustrating this point. It will be noted that the general shape of the curves in all six cases is practically the same, except that with the flat reflectors more light escaped sideways. It will be seen that depolished opal reflectors offer only a limited choice in distribution results, although their efficiency is

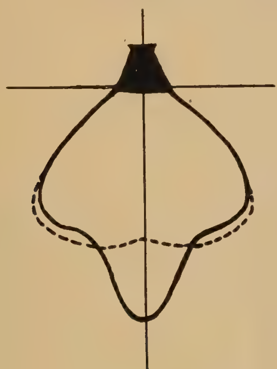


FIG. 27.—Opal Cone Reflector. Full Line—Polished Surface; Dotted Line —Depolished Surface.

high. Inasmuch as this has been fully covered elsewhere,* it will not be necessary to go into the subject further.

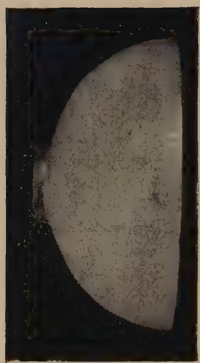
A good opal reflector has a high coefficient of reflection, if clean. The light reflected from such a reflector comes from three different sources:

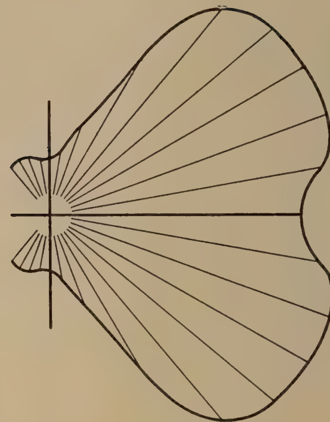
(1) That reflected from the interior glazed surface.

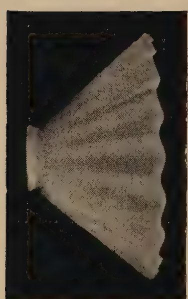
(2) That reflected from the opal particles imbedded in the body of the glass.

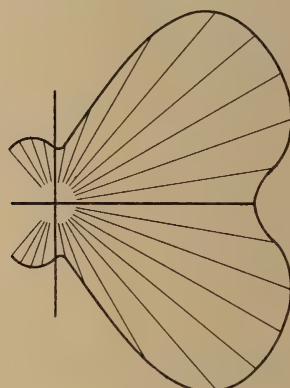
(3) That which passes through the reflector to the outer skin or surface of the reflector, and which, striking at less than the critical angle, is thrown back through the body of the reflector and out.

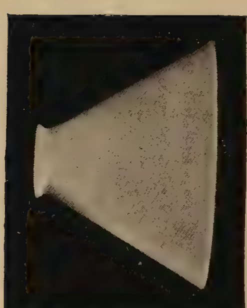
* "Scientific Principles of Globes and Reflectors," in "Transactions" of Illuminating Engineering Society, January, 1910, p. 49.

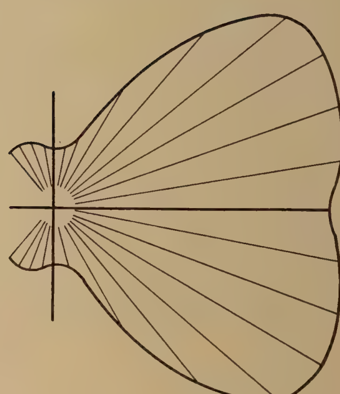












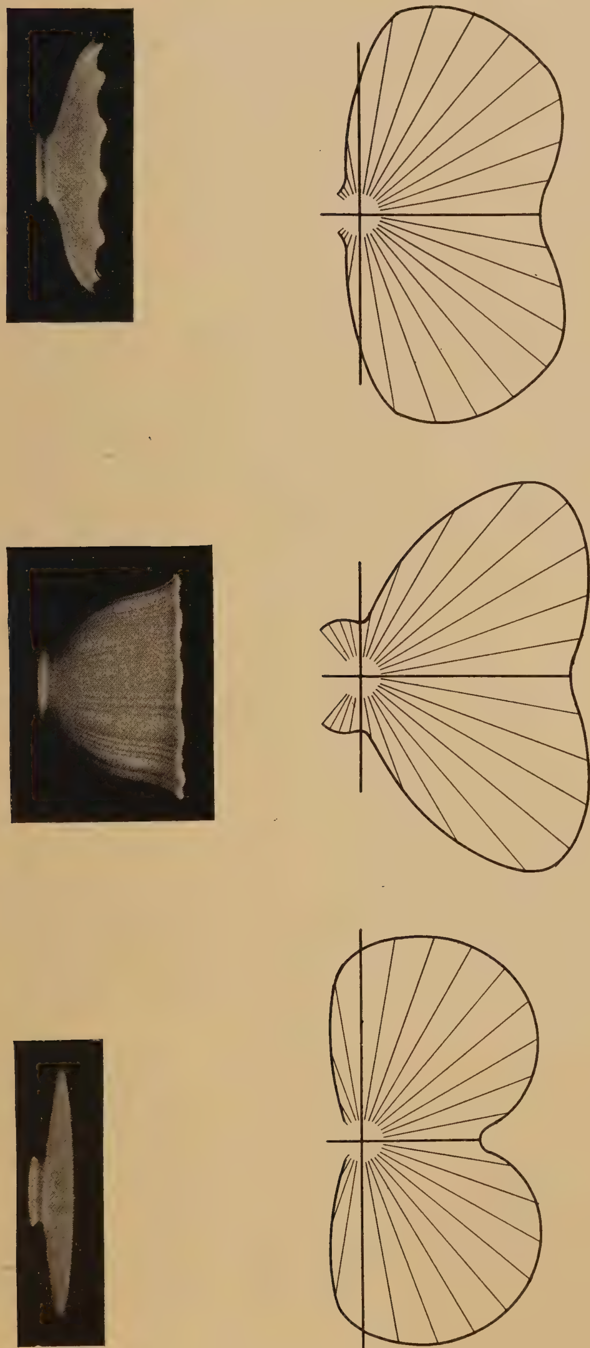


FIG. 28.—Six Differently Shaped Depolished Opal Reflectors Showing Similarity of Photometric Curves.

Fig. 29 shows the photometric curve of an opal reflector.

Fig. 30 shows the same reflector in which the light which passes through the reflector has been cut off by a long, black velvet cylinder. Fig. 31 shows the same reflector with the outer surface painted black. An analysis of these curves shows the following interesting results: Forty per cent of the light is above the horizontal and 60 per cent below. Of the light below the horizontal, 25 per cent is that which has passed through the reflector but is thrown downward, so that only 45 per cent of the light below the

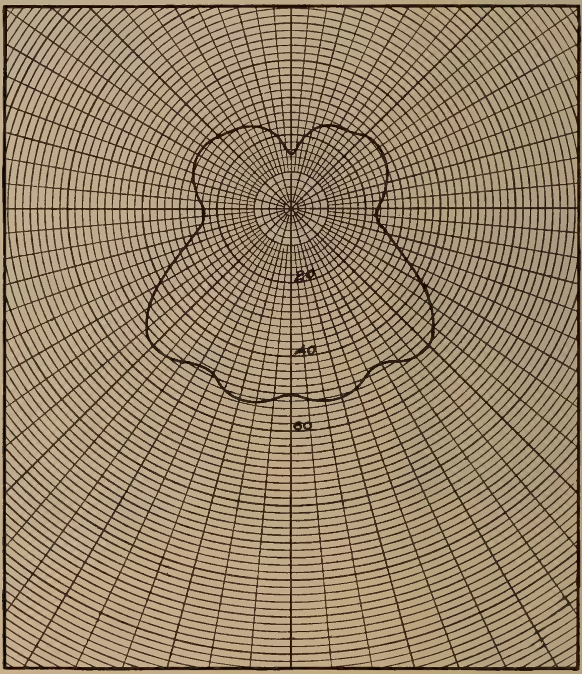


FIG. 29.—Photometric Curve of Opal Reflector.

horizontal has been actually reflected. The balance of 30 per cent, is undirected light emitted by the lamp, and has not been intercepted by the reflector. Of the light which is actually reflected, 21 per cent is due to reflection from the outer surface of the reflector, while the balance, namely, 79 per cent, is due to that reflected from the interior surface and the opal particles. The important point to note in these tests is the high value [21 per cent] which the outer skin or surface of the glass has in its reflecting properties. Of

course, the denser the opal the less this value, inasmuch as all light reflected from the outer surface must pass back through the opal glass, and with a dense opal less light actually reaches the outer surface.

The absorption figures given for such types of glass should be examined with a great deal of care. Claims are made for certain types of this glassware that the absorption is only 3 per cent with a reflector which intercepts most of the flux. Such claims are,

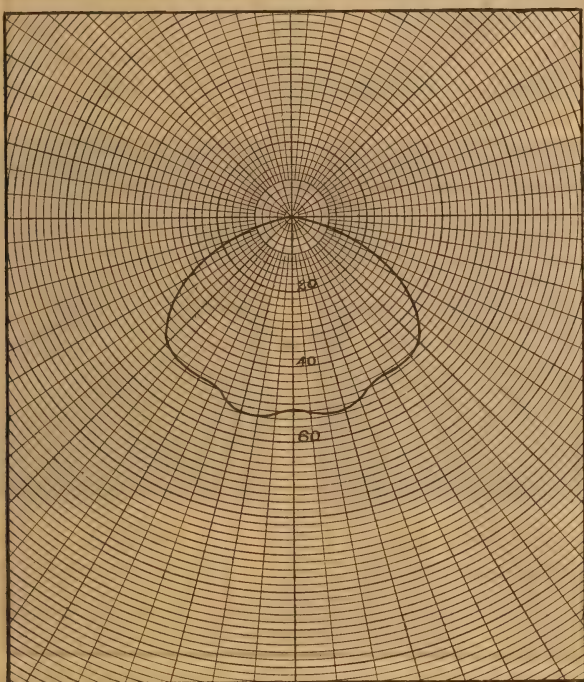


FIG. 30.—Opal Reflector; Outer Surface Covered by Black Velvet Cylinder.

of course, absurd, and result probably from careless testing. Other tests have been published which show an absorption of about 5 per cent, which is almost equally bad. When we consider that clear glass, as used in ordinary shades, has an absorption of nearly 10 per cent, we can readily see that the efficiency of shades of this type cannot have the absorption values often quoted. A thorough and complete investigation of this subject would be of value.

Regular Reflection

Polished Metals, Div. C, Class 12. Polished metals have, as a rule, high reflecting powers. In the case of polished silver we have the highest known value, varying from 84 to 94 per cent, depending on the wave length of the light reflected.* For ordinary white light, this may be considered in the neighborhood of from 90 to 92 per cent. On the other hand, burnished copper gives a yellowish

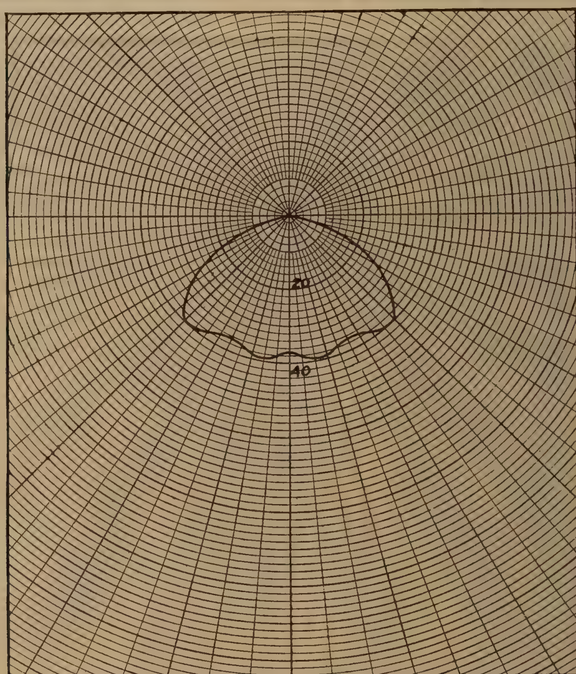


FIG. 31.—Opal Reflector; Outer Surface Painted Black.

tinge to the reflected light, and is of low efficiency. Polished platinum reflects about 60 per cent of the light. Aluminum, which is largely used in ordinary reflector work, has a high coefficient of reflection. Tin and zinc are also sometimes employed with fair results. All polished metal reflectors have one defect, however,

* "Reflecting Power of Various Metals" by W. W. Coblentz, Journal of Franklin Institute, September, 1910; also Wartenburg Verh. Deutsch. Phys. Gesell., 1910, XII, p. 105.

in that they give a streaked light due to multiple images of the light source. Fig. 32 shows clearly the effect of such streaks. Such reflectors, therefore, should be used only in special instances, it being desirable to substitute a depolished surface reflector even if slightly less efficient.

Plain Mirror Strips, Div. C, Class 13. Reflectors of this type have been known for a long while and give a good efficiency. They are generally made up of a tin covering, in which are placed small mirror strips. Such reflectors have been made up largely in cone shapes, and also in troughs for use in window and picture lighting. When new they have a high reflecting power, but are apt to depreciate greatly with age. Depreciation will depend largely upon

Aluminum Reflector—
Depolished Surface.

Aluminum Reflector—
Polished Surface.

FIG. 32.—Showing Streaks in a Polished Metal Reflector.

the quality of the mirrored surfaces used, and also upon the temperature rise of the reflector itself. In case much heat is generated by the lamp, as, for example, in gas lighting, where such a reflector is placed close to the lamp, the deterioration is very marked, and the reflecting power falls off rapidly.

The efficiency of such reflectors is generally much lower than is ordinarily supposed. A finely silvered mirror, in which there is no cross-reflection, never gives over 84 or 85 per cent efficiency, that is to say, 84 or 85 per cent of the light striking the mirror is reflected. The efficiency of ordinary mirror cones in which cheap glass is ordinarily employed, and little or no attention is paid to

cleaning, would probably not be over 70 per cent when comparatively new. When the mirror surface begins to deteriorate, the efficiency will fall off rapidly.

Inasmuch as in mirrored reflectors we are dealing with regular reflection, it is possible to get practically any desired distribution if the reflectors are properly designed. At the present time, however, reflectors of this type on the market are available in only a limited number of distributions. All the cone reflectors give a very strong downward illumination, such as shown in Fig. 33.

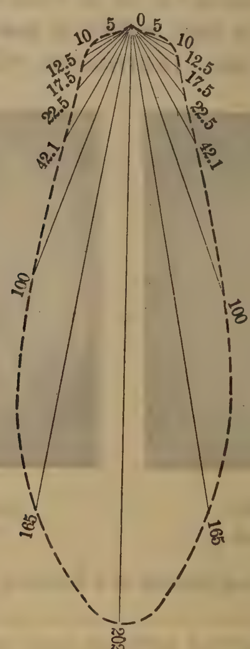


FIG. 33.—Photometric Curve of a 10-inch Mirrored Cone Reflector with 16 Candle-Power Lamp.

In the case of the trough reflectors, there is a wider choice of distributions, as this has been worked out more carefully than in the single light reflectors.

Corrugated Mirror Strips, Div. C, Class 14. The only difference between this and the preceding class is the fact that the mirror strips which go to make up the reflector have a waved surface which is intended to break up and diffuse the light so as to get rid of the

striations caused by multiple reflections of the filament of the lamp. Naturally, this is going to lower to some extent the efficiency, and also destroy somewhat the control of the light, but the corresponding gain in getting rid of the streaks or striations much more than offsets the loss.

Silvered Reflectors, Div. C, Class 15. Silvered reflectors at the present time provide a more effective means of controlling light than any other form of reflector now on the market, with the exception of prismatic reflectors. This is due to their method of construction. The body of the reflector is made of clear glass, which is silvered on its outer surface and then covered over with an elastic enamel, which protects the silvering. Inasmuch as the blown-glass portion can be made in any shape desired, and inasmuch as the reflector acts by regular reflection, it is possible to get nearly any distribution curve desired. The objection to streaks is done away with by putting ribs or corrugations in the glass. The deterioration of such a reflector is very much less than the ordinary mirror-strip reflector. As far as the writer knows, no definite data has been published on the deterioration of this class of reflector, although such data would be extremely desirable. The efficiency of such reflectors is undoubtedly high, probably the highest of any commercial reflectors on the market, if by efficiency we mean the flux of light in the lower hemisphere.

At this point it may be well to call attention to the fact that our present methods of stating the efficiency of reflectors or the absorption of globes is extremely lax. In the first place, efficiency should mean the ratio of the flux impinging on any reflector to the flux reflected; in other words, it should omit the flux from the lamp itself which does not strike the reflector. That this is desirable is at once evident if we consider the efficiency of an ordinary flat porcelain reflector placed at some distance above the light, as is not uncommon in practice. If we should consider efficiency in the ordinary way, namely, the ratio of the total flux of light of the reflector and lamp to the total flux of the lamp itself, we would get an efficiency which might be well over 95 per cent, but if we consider only the ratio of the flux reflected from the reflector to the flux striking it, we would find the efficiency low—probably not over 60 per cent. In considering, therefore, the data which has been published as to the efficiency of reflectors, one should bear this fact carefully in mind. This in itself will probably explain many

discrepancies which now apparently exist. In the case of an ordinary deep reflector which comes down, we will say, to the tip of the lamp, from one-quarter to one-third of the light does not strike the reflector at all. If we find the efficiency of such a reflector as ordinarily stated to be, say, 75 per cent, the true efficiency of the reflector, considering only the two-thirds of the total amount of light which strikes it, would be 62½ per cent. In the case of certain deep types of silvered reflectors of this class, we have efficiency

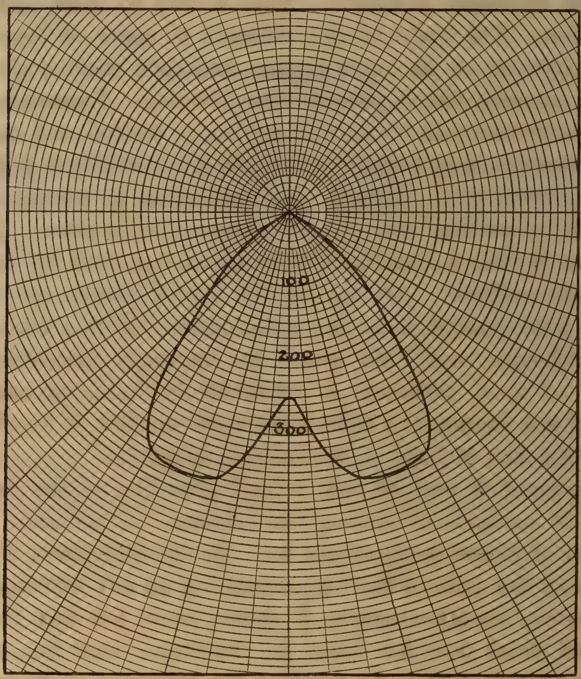


FIG. 34.—Silvered Reflector with 100-watt Tungsten Filament Lamp.

tests varying all the way from 68 to 93 per cent. It is very evident from the foregoing that such efficiency tests are altogether too high. If we consider the efficiency as ordinarily measured, namely, the ratio of the lumens of the lamp with the reflector to the lumens of the bare lamp, it would probably average in the neighborhood of 75 per cent, but when considered from another standpoint, namely, the lumens reflected to the lumens striking the reflector, we would get an efficiency in the neighborhood of 65 per cent.

In dealing with reflectors acting by specular reflection, it must always be borne in mind that if the position of the radiator with respect to the reflector is changed, entirely different photometric results are to be expected. Figs. 34, 35 and 36 show the same silvered reflector used with three different sized lamps, and clearly illustrate this point. It therefore follows that if a reflector is designed for a special sized lamp, it must be used with that lamp to get the results expected.

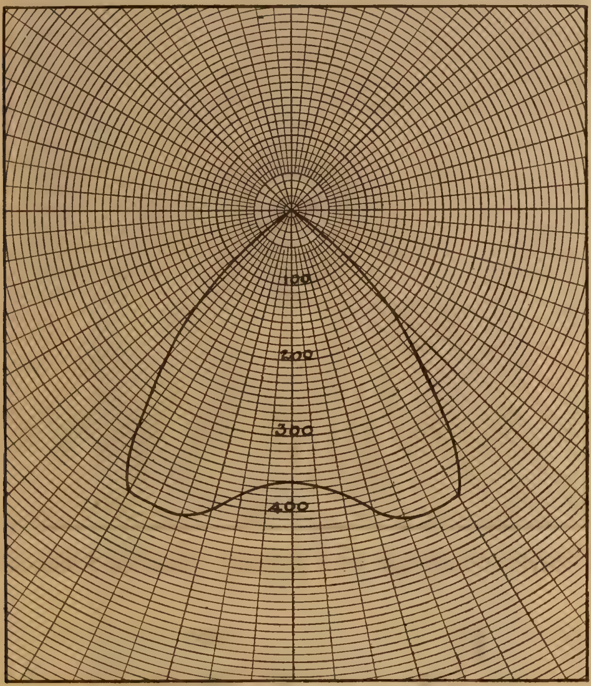


FIG. 35.—Silvered Reflector with 150-watt Tungsten Filament Lamp.

Refractors, Div. C, Class 16. As defined in the first part of this paper, a refractor is a shade through which light is transmitted, but changed in direction by means of prisms. This type of globe or shade was originally invented by Prof. André Blondel, in France, and has seen wide application in this country, where it has been largely exploited. Such refractors give good diffusion, as was more fully explained in Div. B, Class 4. It is possible, also, to materially alter the distribution of light with this type of globe.

Fig. 37 shows an enlarged cross-section of the interior prisms of such a refractor, and illustrates the method of breaking up the light rays.

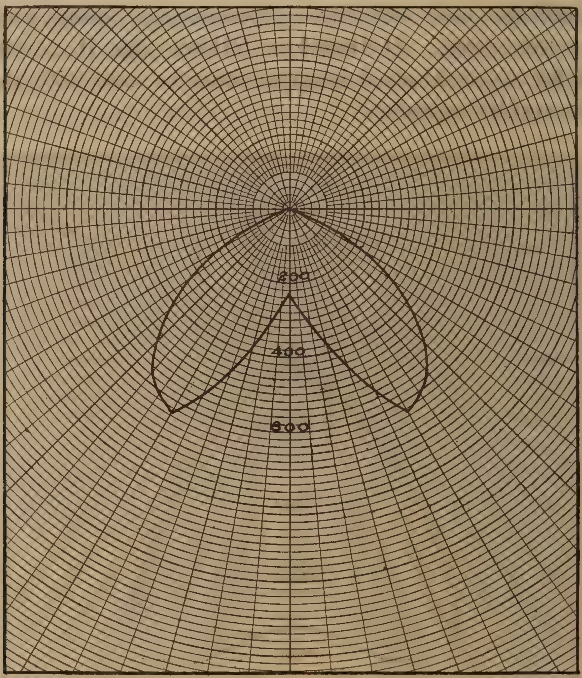


FIG. 36.—Silvered Reflector with 250-watt Tungsten Filament Lamp.

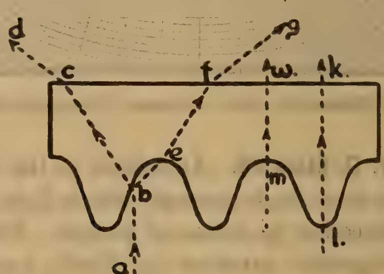


FIG. 37.—Enlarged View of Internal Prisms of Refractor.

Fig. 38 shows a horizontal cross-section of such a globe.

Figs. 39 and 40 show how the light rays are redirected. Generally speaking, there are four faces to each prism; three acting by refraction and one by total reflection. By properly designing the faces of each prism correctly, almost any desired distribution of light can be obtained. Figs. 41, 42 and 43 illustrate three typical curves of such globes as are commercially available. Fig. 44 illustrates an asymmetrical distribution.

In order to get definite results, it is not sufficient to simply rib glass, but each prism must be carefully calculated with reference to the radiator in its correct position. Fig. 45 shows the distribution obtained by a refractor which, in general appearance, was like that whose distribution curve is given in Fig. 41. Not only

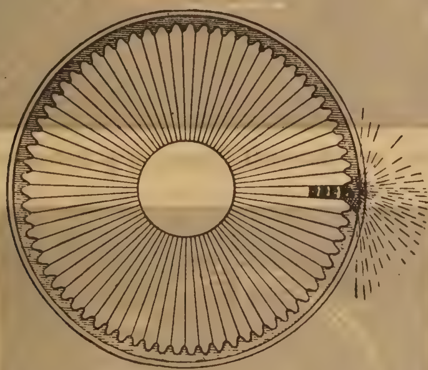


FIG. 38.—Horizontal Section of Refractor Showing Internal Prisms Breaking up Light Rays.

is there no definite redirection of the light rays, but also the absorption is greatly increased due to reasons given in Div. A, Class 2.

Prism Reflectors, Div. C, Class 17. The theory of the prism reflector is extremely simple, and it is rather remarkable that its application to reflectors was not known many years ago, inasmuch as the prism itself has been used as a total reflector in physics for several hundred years.

Fig. 46 shows the path of light in a prism reflector. The light rays, however, only act as shown when dealing with a point source of light. When dealing with a light source of considerable area many complications arise, so that the proper design of such reflectors is not as simple as it might seem at first sight. That this

fact is of practical value will be evident at once from the fact that if we change the relative position of the radiator and the reflector the photometric results are at once changed.

Fig. 47 shows two curves made of the same reflector and same lamp with the relative position of the filament changed, the one

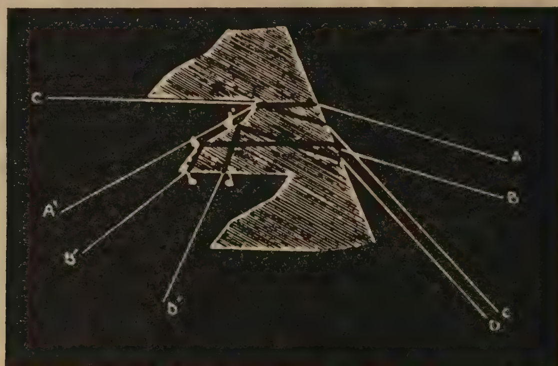


FIG. 39.—External Prisms of a Refractor.

FIG. 40.—Showing Effect of External Prisms on Light Rays.

being used with what is known as a form " O " or standard holder, and the other with a form " H," which is about 1¼ inches deeper. It will be evident, therefore, from this that if desired distributions of light are to be obtained, the proper holder should be used with any given reflector. Similarly, the size of the radiator may alter the distribution of the light very materially.

Fig. 48 shows two photometric curves of the same reflector and same candle-power lamp, one of which, however, is a standard lamp, and the other a special "point-source" lamp of smaller dimensions.

It will be seen from the above that dealing with reflectors acting

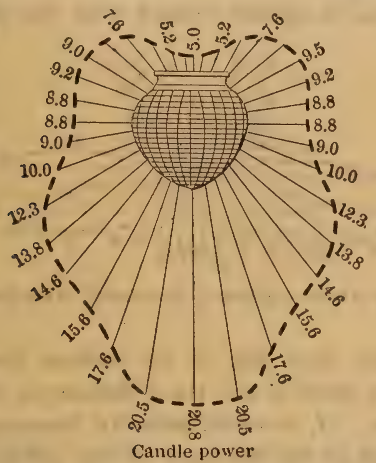


FIG. 41.—Light About a Class A Refractor.

by regular reflection, whether prismatic or otherwise, it is essential to use them in the manner for which they were designed if definite results are to be realized. The problem is not unlike that of the

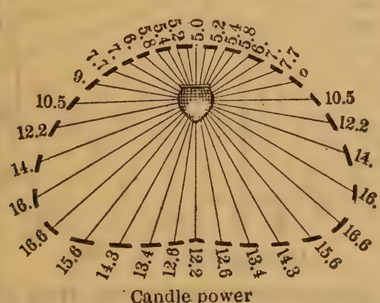


FIG. 42.—Light About a Class B Refractor.

use of ordinary eye glasses, where each pair is intended for definite purposes, and if not used properly poor results follow.

Effect of Dirt. Dirt on the inside of a prismatic reflector has exactly the same effect as on any other type of reflector. The effect of dirt on the outside of a prismatic reflector, however, can vary

all the way from nothing to a large figure. If absolutely dry dirt is placed on the external surface of a prismatic reflector, the efficiency is not decreased; as a matter of fact, slightly more light may be reflected due to the dust itself. The reason for this is that the dirt does not come in optical contact with the glass, and, conse-

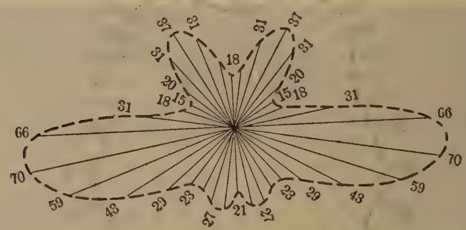


FIG. 43.—Light About a Class C Refractor with Mantle Burner.

quently, due to the thin film of air between the surface of the glass and the dirt, there is still the difference in density necessary for total reflection. If, however, such dirt becomes moist, we have at once a lowering of the efficiency of the reflector, and the loss will depend upon the amount of dirt that is actually in contact

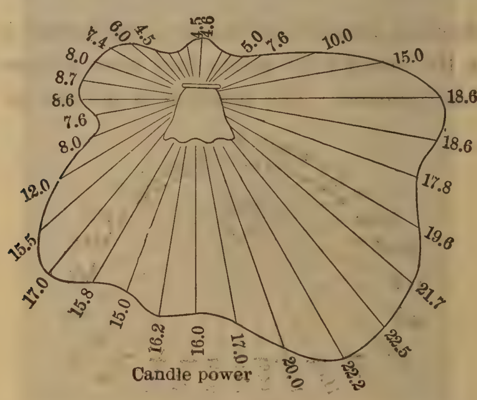
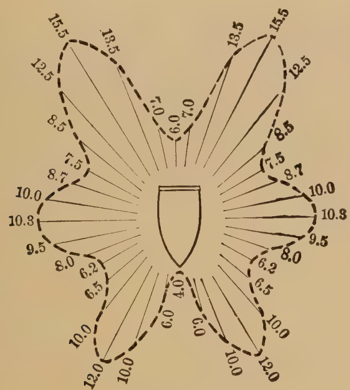


FIG. 44.—Asymmetrical Distribution from Refractor.

with the glass, its thickness, etc. If the reflector should be painted black, the prisms would lose their ability to reflect the only reflection being due to that from the interior surface of the glass and the little which might be reflected from the black paint. It is necessary, therefore, in order to get the best effects from reflectors of this class, to see that they are kept clean.

Effect of Etching. If the interior surface of a prismatic reflector is roughened by sand-blasting or etching, some of its reflecting power is destroyed. The amount will depend upon the depth and character of the etching. There is as much difference between a



Candle Power.

FIG. 45.—Distribution from Uncalculated Refractor.

very coarse sand-blasted interior surface and one which is properly etched as there is between the well-designed and poorly designed prismatic reflector itself.

Prismatic reflectors properly designed are among the most effi-

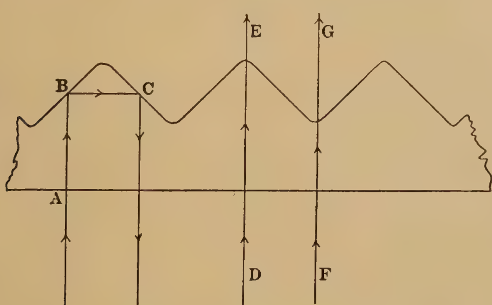


FIG. 46.—Reflection in Prismatic Reflectors.

cient reflectors we have, they being capable of reflecting from 60 to 70 per cent, or slightly more, of the light. In addition, they allow a considerable flux to pass through the reflector, which is of value in lighting up the upper portion of rooms. The absorption

of such reflectors is low, being probably under 10 per cent when properly designed. As explained in Div. A, Class 1, the streaks and striations due to surface reflection are almost entirely done away with in a properly designed prismatic reflector, due to their

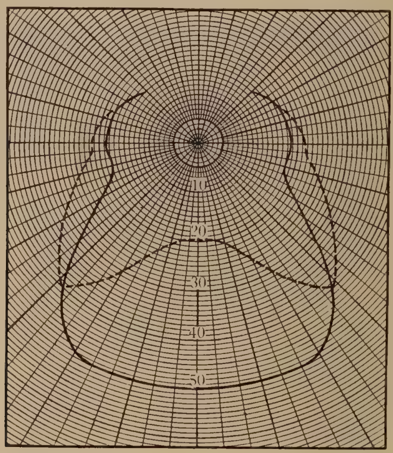


FIG. 47.—Results of Form "O" and "H" Holders with Prismatic Reflector.

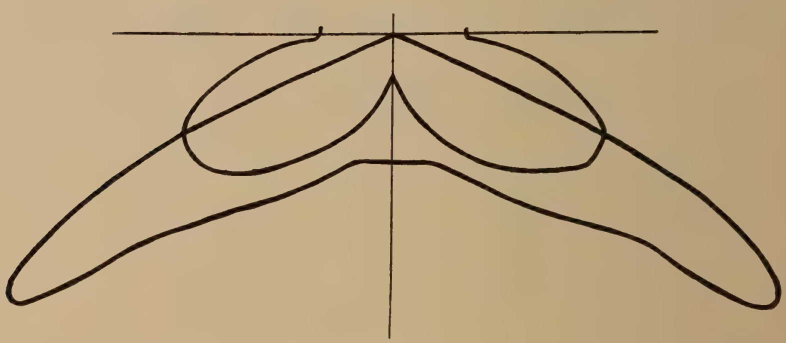


FIG. 48.—Results of Two Lamps of Equal Candle-Power but Different Sized Filaments in Prismatic reflector.

being overpowered by the prismatic reflection. The difference between a well-designed and poorly designed prismatic reflector can be best illustrated by Figs. 49 and 50. Fig. 49 shows two reflectors of identical shape and appearance.

Fig. 50 shows the photometric curves of the two reflectors. The difference in the two curves speaks for itself.

Photometric Curves. Inasmuch as prismatic reflectors act by regular reflection, it is possible to obtain any desired distribution curve through wide limits.

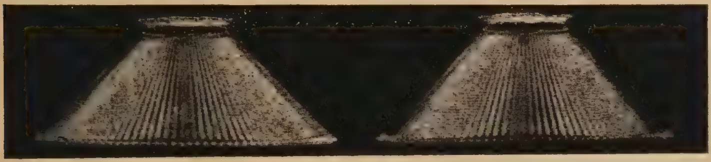


FIG. 49.—Two Prismatic Reflectors of Identical Appearance.

Fig. 51 shows the well-known extensive, intensive and focusing of distribution from prismatic reflectors.

Fig. 52 shows the horizontal distribution curve of an asymmetrical prismatic street lighting reflector, and illustrates the possibilities of this type of construction.

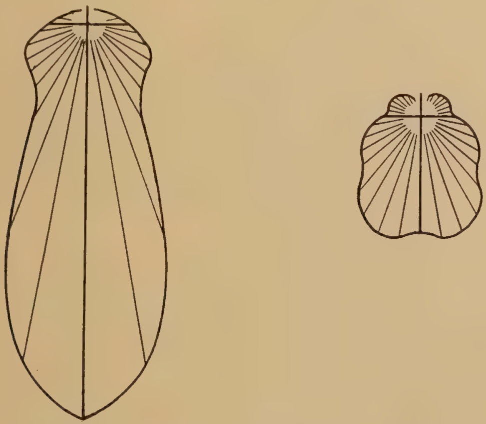
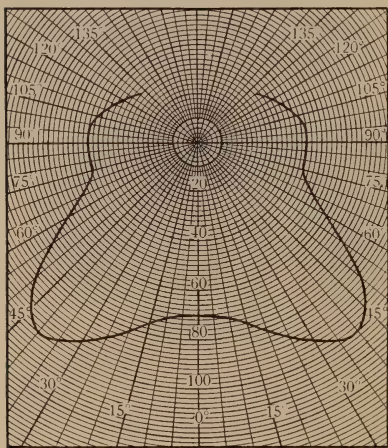


FIG. 50.—Photometric Curves of Reflectors Shown in Fig. 49.

Conclusions. There are naturally many parts of this subject which have not been touched upon, such as, for example, combinations of different shades and reflectors, indirect lighting, semi-indirect lighting, car lighting, etc. Sufficient has been given, however, to show that we have at the present time a comparatively small amount of exact data on this subject, and it is highly de-

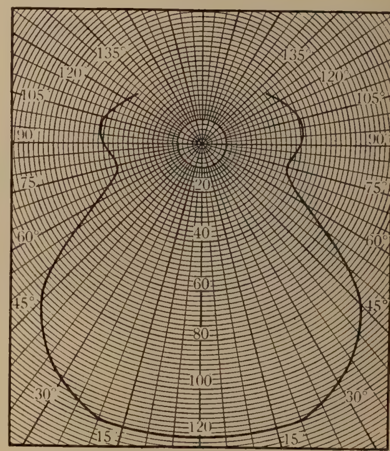
Characteristic Curve for Extensive Reflector.



100-watt, 80 c. p. Frosted Tip, Tungsten Lamp.

FIG. 51a.

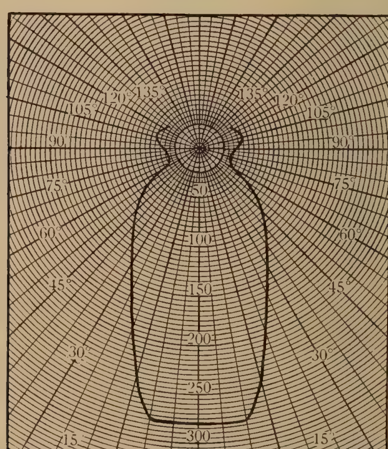
Characteristic Curve for Intensive Reflector.



100-watt, 80 c. p. Frosted Tip, Tungsten Lamp.

FIG. 51b.

Characteristic Curve for Focusing Reflector.



100-watt, 80 c. p. Frosted Tip, Tungsten Lamp.

FIG. 51c.

FIG. 51.—Photometric Curves of Extensive, Intensive and Focusing Types of Prismatic Reflectors.

sirable that investigational work be carried on to find out definitely many points about which at the present time we know little or nothing.

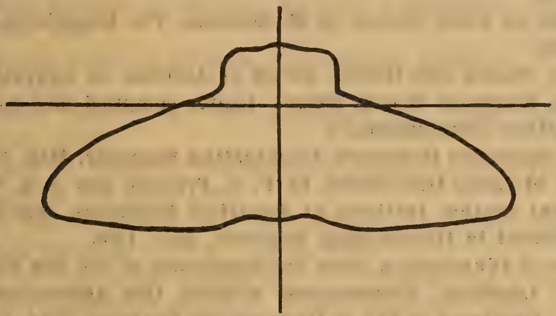


FIG. 52.—Horizontal Distribution from an Asymmetrical Prismatic Street Lighting Reflector.

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XVI

LIGHTING FIXTURES

By Edward F. Caldwell

CONTENTS

History of electric light fixtures.
 Modification of gas fixtures.
 Requirements of Board of Underwriters.
Present requirements.
Design. Competition with French artists.
Principles of design.
 Question of imitation of candles, etc.
 Use of old and new chandeliers.
Relation of fixture to room.
Two extreme types of fixtures called for:
 a. Plain, undecorated, geometrical.
 b. Ornamental, elaborate, but of fine workmanship.
 Necessity of consulting the purchaser.
Influence of the illuminating engineer upon design of fixtures, e. g., number of outlets in a room.
Importance of proper design.

With your indulgence, and as a preliminary introduction to the subject which I have been asked to talk about, I would like to say a few words about the history of the industry of electric light fixtures within the last 30 years. It might be interesting for you to know under what restrictions this industry has arrived at its present condition, and also how many obstacles it had to overcome to reach a point of efficiency.

In the beginning, the lighting fixture industry was concerned with the making of fixtures for oil, and, probably, for the 10 or 15 years in which the manufacturers were active, little or nothing was done towards an improvement of the designs of the goods that they were making. When first making fixtures for gas, manufacturers followed closely upon what was made in England and abroad of the cheaper character, and paid little or no attention to improving their own designs or attempted to do anything excepting to make a commercial venture profitable. It was not until

the exhibition at Philadelphia in 1876 that a decided impetus was given to the artistic side of the industry, and from that time up to the present there has been a decided change for the better in all that affects the designing as well as the making of all goods that were to be used for lighting purposes.

However, it was not until electricity was introduced that the manufacturer really began to contend with the numerous difficulties that the many means of illumination brought to complicate the nature and character of his business. In the beginning, the wires were run on the outside of the arms; the light was pointed down, and the ordinary gas fixture of commerce was utilized by the simple attachment of bulbs, or, perhaps, in some instances, the reversing of a design to answer the purpose. It was a matter of perhaps 10 years before any decided step was taken towards a distinct improvement in the character of electric lighting fixtures. There were many years in the art of electric lighting, however, when the fixtures were very unsatisfactory and crude. The making of the fixtures themselves was surrounded by numerous patents; in the early history of the art, the people who connected with design the making of the simpler fixtures covered everything that was used with a patent. The other manufacturers, when they came to the question of making fixtures for the purpose of lighting, found that almost every device and every method was put beyond them by the mere fact of these patents. Then came a long period of litigation which covered practically the entire life of the patents and some renewals; they were all disposed of with the exception of one, which, being a fundamental patent, still prevented the general manufacturer from having a free hand in the advancing of the industry. The insulating joint, which was an essential feature of all installation, was protected by a patent which it seemed to be impossible to break; it held its force through years of fierce and expensive litigation, until it was decided invalid only a short time before its final expiration. During all this time, the different manufacturers were making all the efforts they could to improve, both artistically and technically, the product of their factories. In addition to these difficulties came the constant and ever-recurring change in the requirements of installation and supervision of the Board of Underwriters; their code of rules for the installation of all electrical appliances was being constantly added to, much to the discomfort and anxiety of all engaged in the manufacturing of

electrical fittings. The general tendency on the part of all installation work to leave out switches and rely upon the fixture itself as a means of turning on and off the light had also added to the difficulties. All of these things tended to focus the mind of the manufacturer upon the things to be avoided in his business rather than to the things to be realized in the way of an improvement in design and methods. On the expiration of the patents, upon a thorough knowledge on the part of the manufacturer as to what was required of him from the Board of Underwriters, when he knew exactly how he could make his fixtures, and the size of the wires that were required to be used, he settled down to adjusting his designs to the necessities of this supervision, and for the last 10 or 15 years the lighting fixture industry of this country has made a rapid and decided improvement, not only in design, but in the character and quality of the goods produced.

I have been keenly alive, within the last few years, to more or less apparent criticism of what people have been inclined to discuss as a lack of progress in this industry. Comparing it with other trades concerned in the furnishing and decorating of our private houses and public buildings, I am of the opinion that it has held its own, and perhaps even done better, considering the great technical difficulties it had to overcome. In the beginning, a concern manufacturing, as we do in this country, the fixture in its entirety, has to gather about itself a great many capable and intelligent workmen, skilled mechanics, modelers, sculptors, moulders, coppersmiths, blacksmiths, gilders, chasers, chiselers, and numerous others whose vocation is more than a trade—it is an art. Men of this kind, in a country such as ours at the period of which I speak, hardly existed; they had to be brought here by the inducement of higher wages and steady employment. Certain parts of these industries were entirely unknown, and were not even practiced at that time by anybody in this country; fine gilding, and the making of false-core castings in bronze or brass were then comparatively unknown; the men to do these things had to be brought here; the other men who entered into the manufacturing of these finer goods also had to be brought here, and with the nucleus of these men the trade was taught to others; and to-day one of the greatest problems facing the manufacturer is the securing of a sufficient amount of this skilled labor to properly perform the better class of goods which he is called upon to make.

The question of design became a very important matter; in the beginning, the manufacturer was called upon to compete against the manufacturers of France, who were the beginners in all that was admirable, both in design and manufacture, of all articles in bronze. Having every facility, not only for the study of the designs applicable to the wants of the public, they had the tradition of their workmen as well as the many examples in their museums. The American manufacturer was without these examples, and could only obtain, through photographs or short visits to the other side, some ideas of the accumulation of motives and designs applicable to the business in which he was engaged. I speak of this as showing the difficulties that the manufacturer in this country labored under in the beginning, in attempting to compete with the foreign manufacturer, for the foreign manufacturer had most decidedly the advantage of him in regard to design and finish, and was at that time monopolizing practically all the very fine business. He was forced to import and copy, to make periodical visits to the other side with a view of buying and acquainting himself with what the French were making for he found here in this country that all of our decorative schemes were founded upon a French origin, and the classic styles of Louis XIV, Louis XV, Louis XVI, and others, were the styles that he had to design in keeping with. He also found that the attitude of the buyer was prejudiced largely in favor of the foreign article, that the progress made in matters of this kind in this country had been slow and, to a large sense, unsatisfactory, and the concensus of opinion of the buying public was largely in favor of getting things of this kind from abroad.

This was the situation that confronted the manufacturer in the beginning of the use of electricity in this country; it is, in a way, the situation to-day as far as the prejudice of the public is concerned; there is a feeling on the part of many people of taste and wealth that things of this kind are bought to better advantage in Paris or London than they are in New York, and it is a hard and difficult matter, even now, to convince many of them to the contrary. These were part of the many difficulties the industry had to go through with, and it represents one of the many obstacles that it had to overcome.

The quite frequent reference on my part to the foreign competition and the foreign maker needs, perhaps, a little explanation. In the first place, I am talking from the standpoint of one whose

designing for electric lighting has been very largely connected with private house work and a better class of fixtures; you will find that my references are largely to this condition when I speak of a condition in the trade; these conditions of the industry to-day have been largely influenced by the migratory habits of our people. The average person of wealth is a traveler, and if he is building a house is largely influenced to buy what he sees abroad; the tendency to buy over there is strong, and the tendency to make comparisons is also strong. The average decorating house in New York is largely committed to advising the use of foreign fixtures, for some reason which he himself can better explain than I can; and we find that competition is not confined in our industry entirely to ourselves, but is confined to the foreign manufacturer and dealer as well; their trade has been large in this country, and their influence has been felt, and it became a matter of absolute necessity to the manufacturer here that the standard of what he made, artistically both in design and finish, should reach the standard of the foreign manufacturer; otherwise he would fail to succeed. This, probably, has been one of the greatest stimulants to the advance of the lighting fixture industry, and has, perhaps, been the main factor in bringing about a satisfactory result; I have no hesitancy in saying that, in some respects, we are now quite able to compete successfully with even the best French manufacturers, and have, in some particulars, a decided advantage over them in the fact that we have applied our inventive talent to many styles besides those which are distinctively French, and have utilized wood, alabaster and marble to a point that the foreigner has never yet attempted, and of late years have turned our attention to the designing of fixtures that met the requirements of English styles of decoration which have been very much in vogue within the last few years.

It must be admitted that the fixture business is in nearly all particulars essentially an artistic one; there is no use of evading this question, because it belongs in every particular to the adornment in detail of our interiors; whether it is a store, a factory, a dwelling or a building used for civic purposes, monumental or domestic in character, the fact remains the same that there is very little excuse for it if it does not render itself as attractive as possible in line and appearance. All who use these things have a right to expect it, and there is no reason why the manufacturers should not meet this demand; that they fail to meet it in many

particulars goes without saying, from the fact that many people are engaged in this industry to-day with a purely commercial instinct; it is a means with them of making a living; it is so here, it is so in other countries, and it always will be so, but any concern arriving at any importance in the business world, and that fails to consider its duty to itself and the public in this one particular, cannot successfully carry on its enterprise. I am free to say that in the majority of instances the larger and leading manufacturers in this country to-day are capable and competent, when it comes to a question of artistic result. I am forced to confess, however, that there are many engaged in this work whose output is not large and whose efforts are ambitious, but who fail to understand the artistic necessities in a great many cases; they fail because they underestimate the importance of the designer and the value of an aesthetic side to their production. These men, unfortunately, are likely to figure in competitions and, in many instances, are successful in their efforts; price is so apt to play a large part in the question of a competition that they succeed largely where the question of price is the main thing to be considered.

As a representative of the manufacturers, as one who has been engaged in the industry for many years, it is with great pride that I am free to say, without any desire to over-estimate, that the American manufacturer to-day has made a progress which, in my opinion, is not only unusual but worthy of the greatest admiration, and for which he should receive the greatest credit.

Having disposed of this part of the subject, I will apply myself, gentlemen, in a general way, to that part of my lecture which deals more directly with the present and with the question that concerns us all. In the first attempt to adapt artistic fixtures to the question of lighting, France unquestionably led the world, and, as far as my memory goes, nearly everything at that time was made with the light turned down. At first, in adapting all of their old designs, they adapted them with a change which either involved turning the light down or pointing it at angle of 45°. It was not usual for them to use the fixture with the light pointing up. In time, however, the tendency was with them, as it also grew with us, in all the better grade and class of goods, to return to the original method of design as adopted in the candle fixture, and turn the lights up, using a lamp of small candle-power on top of an imitation candle—a practice which has been condemned very severely in

some quarters, and I find now that there are certain few people who have a distinct prejudice against what they consider to be a violation of artistic conditions. The theory as to whether the electric light should be purely and simply an electric light, and stand for such without trying to disguise it and make it look like a real candle, is largely one of prejudice and sentiment; personally, I see absolutely no reason why the electric light should not be used in any way that one chooses to use it, providing they do not make it offensive to sight, and providing it harmonizes with the surroundings. I am inclined to believe that the designer had very little to do with the question as to whether the light should be turned up or down; I have come to the conclusion that questions of this kind belong largely to the prejudice of the public; the decorator looks at these things from a large and varied point of view and settles them not, perhaps, so much from his own standpoint as from the standpoint of the many people with whom he comes in contact. The result is that prejudice and methods that existed in the beginning have changed, by public sentiment, into what is looked upon generally as the proper method of carrying out the idea. The practice to-day of electrical illumination, as it is carried on within the limits of private house work of a certain high grade and character, is as clearly marked as the different orders of architecture; conventional ideas prevail, and I am free to say that no designer, unless he designs on a different basis from what is generally accepted can expect to have anything excepting the conventional type of fixture accepted. I would say further that, as a matter of fact, the designer of an electric light fixture to-day, in approaching almost any proposition that is brought to his attention, has, to a very large extent, the conditions laid out for him; the style of the room is settled, the general type of the fixture is firmly fixed in the mind of the buyer, and the designer is supposed to work and design within the limits of certain restrictions. There is very little reason to suppose that a designer goes on constantly creating new forms and new shapes, and evolving original ideas constantly for the use of electrical illumination; such a thing would be practically impossible from the fact that he, his work, and his design becomes, in time, only a part of the whole, and he is to the chair itself what the guimpe or the tacks might be—a part, an accessory, which must harmonize and be in keeping, and in the same general and prevailing style and tone. It is, therefore, im-

possible to formulate any rule or plan for the designing of electric lighting fixtures; it is hard to tell what to avoid, and what to adopt; we find, for instance, that it is prevalent with the French of to-day to point their lights up on all the brackets and chandeliers which they have in general use; and we also find that they are reverting back to the old and primitive types of chandeliers and brackets that were used for candles; further than that, they are using these old types and shapes in exactly the same way in which they were used for candles. This is the result of many years of change and endeavor, and naturally raises the question as to whether an imitation candle, made of porcelain or metal, with an electric bulb on the top, instead of the real candle itself, is a proper conception of an artistic lighting fixture; cover the light with a silk shade, shield it from the eye with some soft material, complete the illusion by toning your candle to the exact color of the wax, and the effect becomes absolutely the same; then, why should there be any criticism? The fact remains, however, that it is not a candle, but the fact cannot affect, in any sense, the effect that it has upon its surroundings or upon its environments.

The making of electric lighting fixtures, as I have said before, is an art that belongs to the proper furnishing of the room; by the very nature of things, it becomes a part of the room; it should harmonize in style, be of the proper proportion, be of the proper finish and workmanship, and the proper color of gilding. Having said this, what more can be said in regard to what the fixture should be? It then becomes a question of the elaboration or the simplicity, of the good taste and judgment of the man who designs it; the tendency is, however, in my opinion, on the part of nearly all who are concerned in designing fixtures of this type, to adhere to the old motives and reproduce the old examples. There has been a great deal of criticism of the lack of initiative in fixture designers, but I think the fixture designer has done this thing, in a large sense, from the fact that it is what the public expects to get, and it is his business, as a business man, to supply the public with what it wants.

It was my intention, when I first began to take notes for this lecture, to say something at length of design and designing; I have found the subject too elusive; the principles that underlie the art of design are so varied and, in a sense, so indefinite, that I hesitated to discuss in theory a matter that I know well only in practice. To try and explain in any way the underlying princi-

ples of proper design requires one with more faculty of expressing and a better knowledge of the use of words. I know that the talent for clever expression in drawing is not to be confounded with that of pure design. My recollection of the quotation on the first page of the first book on drawing that I ever owned, that "One who can learn to write can learn to draw," at the time involved to me, in its meaning, the whole question of art. I found, in time, it did not; one can learn to draw—each within his limitation—but one cannot learn to design any more than he can learn to color; great designers, as well as great colorists, are born, not made. I hold a great facility in a designer, as a draughtsman, to be a detriment in most instances; the desire to make a thing look well in the drawing diverts the mind from the thing itself. The tendency that all clever draughtsman have to consider the thing more or less as a picture than as an object defeats their efforts, and they are apt to find a design that is full of the conceit of clever expression does not please when made and put in place.

There is one question that interests the connaisseur and the designer more than any other, and that is the relation not so much of the light to the fixture as the workman to the design; in the minds of many people of good taste and discrimination, a simplicity of outline and detail is all that they ask for and all that they expect to get; their houses are furnished in a simple and direct manner, with an elimination of anything that tends towards detail or richness of design. A great many things that are interesting artistically are naturally left out of a house of this kind. On the other hand, a man equally well educated, just as much of a connaisseur, just as particular in his ideas as to what constitutes a proper interpretation of art, will insist that his designs have something more than a mere shape and form, and that they represent in themselves a high degree of workmanship and great beauty in finish. One person absolutely refuses to have any form of ornament in the house which embodies a bowknot, basket, mask, or anything that is symbolical, and insists that all ornaments should be without any particular significance, that only the motives of plant form and geometrical designs should be used. The other person has no objection to any form of design, providing the execution represents great skill, ingenuity and artistic finish. What is one man's meat is another man's poison. What is good in the opinion of one man becomes poor in the opinion of another, and in

choosing between the two persons you would be at a loss to know which was the more capable and which the better posted in all the elementary ideas of art and practice. A designer, in time, learns to see the perfect fallacy of having any absolutely decided opinions in regard to design, and if he is a man of large experience and wide culture, accepts anything and everything that shows in itself an intelligent rendering and a skillful craftsmanship; the higher the art is carried, although it may be over-ornate, the more the color and the greater the elaboration, the more it appeals to him. It does not follow, however, that he is called upon to offer it to the first party that comes along; his position in the business world tells him that he has to find out what the peculiarities and idiosyncrasies are of each and every one he meets, and adapt his talent and his art to their requirements.

This may sound like dodging the question, and undoubtedly is, in a way, but a designer of a thing as practical and elementary as an electric light fixture generally has to do these things for the public, and the public have to be pleased; otherwise, he would find no output for his product and no appreciation for his talent A designer who is able to preach a doctrine entirely his own, or able to inoculate a system for which he is entirely responsible, is a man who is going to find it extremely difficult to market many of his wares; all people of good taste do not think alike in regard to what constitutes the proper thing in regard to an electric lighting fixture.

I have felt, while noting down the few remarks I have made to you, that I could have talked more intelligently if I had a specific subject to talk about. It seems as if I had rambled a good deal and have said very little; this is largely the result of the lack of pliability of a mind which has been used to deal with facts in the concrete, and had very little to do with things in the abstract. There is, generally speaking, a reason for almost anything that is done in designing, providing a man is conscientious and is working up to a purpose. After years of study and application, he finds, naturally, that certain forms, certain shapes, and certain materials are necessary for the completion of his idea, but it is extremely difficult for a man to discuss these things and say very much that is worth while remembering unless he has the objects themselves in front of him to demonstrate the meaning of his words. Having made it a practice, largely, of using a pencil in addition to his

tongue in enforcing his ideas upon the public, it becomes difficult, at a period like this, to make himself clear without the aid of his pencil, and he realizes that he might make his point much more effective if he had a picture to show, or even the article itself.

The taste of the public is a thing that one is bound to consider; no one knows it more thoroughly than the business man with his 300 workmen who have to be provided with work, and that he has got to take this work and deliver it at a profit. This fact behind him may sometimes work to the detriment of his intentions, but I can see that this is one advantage, in my opinion, that the illuminating engineer of the future may have, in the fact that his position is purely a professional one, and that his vocation is largely one of an adviser. Whether he will be able, in time, to master the intricacies of design which have become so much a part of the necessities of the case is for the future to tell us; but one thing is very certain, that his influence cannot extend to a very large extent unless he has mastered, in a degree, the art of design as well as the science of illumination, if it is his intention to manage the whole thing.

The illuminating engineer will be able to rectify, in my opinion, many abuses and many conditions that are detrimental, that still exist and will exist from the mere fact that the manufacturer has no intention to change them. The first condition of importance is the question of the less important fixtures that enter into the furnishing of all our buildings, not only the private building, but the building for commercial and civic use. The small brackets and small lights which are now made of an inferior material and poor design should be replaced by fixtures of a better and higher grade of workmanship. The designs themselves are bad, notoriously so from the fact that so little is generally paid for these goods. I have noticed, in the few designs that have been sent out by illuminating engineers for competition, that they have improved the nature and character of the manufacturing, increased the sizes of the materials used, and the weight, and insisted upon better construction; they have still adhered, in most cases, to the obsolete form of design. Having this matter entirely within their own control, it would have seemed a simple matter for them to have adopted a type, though it might have cost more, which would have been a great deal more in keeping with the surroundings. The methods employed in the beginning to make installation easy have been kept

up to the present time. Large and ugly shaped backs, which were made to slide, were used in order that the fixtures themselves should go up without much complication. Large boxes were used in order that one type might meet all cases; 4-inch junction boxes, which was the general type of junction box used, had to be covered, in almost all instances; therefore, large backs over 4 inches in width with a projection of at least 2 or 3 inches or more had to be used. All of these conditions could be overcome by putting a cover on the box and reducing the size of the backs and the general character of the design to a much more suitable and appropriate condition.

The regulating of competition, selection of competent manufacturers, the equalizing of the importance of the designs, and the writing of specifications that would clearly and comprehensively cover the requirements involved, will, in my opinion, all tend towards a better result. This is not going to be an agreeable change to the manufacturer, nor is he going to receive it with any kind of complaisance, but it is all in the direction of improvement, and if the proper amount of care and attention is given to the designing, there is no reason why the other questions involved could not only thoroughly but well be taken care of.

Up to a very recent date, very few of our public buildings have had the proper amount of attention given to the question of lighting fixtures; the appropriations have never been large enough to cover the great number of outlets that are installed, and the result has been that cheap expedients, in many cases, have been resorted to, to get fixtures of a proper size and importance. The introduction of plaster and wood as a means of making fixtures has made it easy to make large things for little money; whether a plaster fixture put into a State capitol to remain there for time immemorial is the proper material for a such thing is a debatable question. The permanency of bronze and marble has never been questioned, and we all know that an architect, if he can induce his client to use marble, will never use plaster unless it is a place where plaster is imperatively called for.

The illuminating engineer, I hope, will also have something to say about the disposition of outlets, and will be able to control, with his precise knowledge of light, a minimum of outlets in a room; so that, when the time comes for the question of fixtures, he can supply, with his appropriation of $10,000 (we will say, for

instance), the minimum number of 50 fixtures instead of the maximum number of 100. I have found, in many cases where I have been called upon to compete, a condition existing where a large number of outlets were put in as a mere matter of precaution, the architect saying that if they were not wanted they could be eliminated. This does not seem to me to be good practice; when a matter of this kind is put into the hands of an expert, he should be able to tell what outlets are needed and the amount of light required, but to put in outlets for five chandeliers and only use one, because only one was really required, seems to be a complication in all directions, for it forces the fixture man to bid on five chandeliers at $50 apiece when he would much rather have bid on one chandelier at $150.

These questions, and many others which might be interesting, so closely concern the duties of the illuminating engineer that, in the future, he will probably find the advantage of his position will be great; that his opportunities for correcting many abuses will be evident, and that he can bring about not only a more satisfactory condition for the architect and the owner, but can also introduce into our public buildings a better and higher grade of fixture than have been heretofore used. The insurance people will tell you that the badly made and badly constructed fixture is one of the most dangerous parts of the present electrical installation, and that they would be willing to welcome anything that would give them relief in this direction; this refers principally to those fixtures which are used in the minor parts of all buildings and which, to-day, are sold for a mere nominal sum, and sold for a nominal sum because they are not only made of a cheap and light material, but are badly constructed, and in a general competition it is almost impossible, where the manufacturers are bidding under a general competition and against each other, to raise themselves above the general level of what has been, and what is existing.

XVII

THE COMMERCIAL ASPECTS OF ELECTRIC LIGHTING

BY J. W. LIEB, JR.

CONTENTS

A. C. and D. C. Supply.
Lighting.
Street Lighting.
Power Service.
Heating.
Storage Battery Charging.
Continuity of Service.
Voltage Regulation.
Adequate Equipment in Stations.
"Human Element."

6. Accounting—Operating Costs and Fixed Charges.
N. E. L. A. "Accounting System."
Construction and Equipment.
Operating Accounts.
Analysis of Revenue.
Depreciation.
Bond Interest, Stock Dividends, etc.

7. Rate Schedules.
Philosophy of Rates.
Flat Rates.
Rate Differentials.
Horse Hire Analogy.
Rate Discounts.
Wright Demand System.
Kapp System.
Wholesale or Bulk Supply.
"Breakdown" Service.
Railroad Service.

8. Metering.
Limits of Accuracy.
Conditions of Test.
Municipal Requirements.
Approval of Types.
Fast and Slow Meters.
Periodic Tests.
Complaint Tests.
Maximum Demand Meters.
Location of Meters.

9. Advertising and Canvassing.
"Show Rooms."
Agency Service.
Illuminating Experts.
Power Experts.
Newspaper Advertising.
"House Organs."
Electric Signs.

The field covered by the title of this address is so vast, and it includes such a number of details that it is hopeless to attempt to give more than a general outline of the subject within the brief period allotted for its oral presentation, or within the limits of a single paper.

The Public Utility Corporation

The corporation assuming the business of supplying electric current to a community for lighting purposes usually distributes it, from the same circuits or from special circuits, for power purposes also, and incidentally for heating; it will be understood, therefore, that where reference is here made in general terms to the lighting corporations or central station companies, it includes broadly the business of the generation and distribution of electric current for light, heat and power purposes.

Corporation Organization. The electricity supply company in New York State must be organized under the provisions of the Transportation Corporations Law, a general statute applying to gas, electric and similar corporations. In most of the other States there are somewhat similar statutes. The corporation organized is the creature of the State, enjoying certain privileges and assuming reciprocal obligations toward the State, the municipality and the public. The company is, however, still incomplete and unable to do the business for which it was organized until it receives from the authorities of the municipality where it is to operate the right or franchise to occupy the streets. This right is a grant or special franchise from the sovereign power, the State, received through the local legislature, board of aldermen, selectmen, etc. When this grant has been conferred upon the company it is ready to commence operations.

In this presentation we shall have to deal more with the rather indefinite and almost indefinable obligations which the corporation assumes towards the public at large and towards its consumers than with the conditions under which it has obtained its charter and established itself as a business corporation with the right to use the public domain. It will not be practicable, therefore, to discuss at length the form of the business organization, its officers and their respective duties, or the scheme of departmental or bureau subdivision of the business; nor will it be profitable to

present an ideal scheme of organization, as it will be found that the duties and responsibilities assigned in conformity with it to the executives and officials depend so much upon the personality and experience of the individuals, that while it is theoretically possible to devise a general scheme of classification of duties it is usually difficult to make the ideal scheme fit any set of actual conditions or any particular set of men.

Franchises. When the electric lighting industry was in its infancy the municipal authorities were eager to obtain for their communities a prompt application of the new developments, and franchises could be readily obtained for the asking that were broad in character and perpetual in term. New developments in the electrical industry were exploited by the manufacturing companies which eagerly sought franchises from the municipalities, if not for themselves at least for their local agents or company, often for the ultimate purpose of selling the machinery or apparatus manufactured by them. Franchises were freely given by the municipal authorities on varying terms. Thus the manufacturing corporations representing the different systems, such as Brush, Edison, Thomson-Houston, Ball and Waterhouse, and others, were very early in the field of electric lighting. The franchises or privileges granted to these companies were somewhat similar and differed only in the variety of conditions to be complied with, and which the local companies were willing to assume. These franchises were usually perpetual, but where the question of the life of the franchise was considered as of serious moment, a restriction to a 50-year period was at times imposed, and often some consideration was demanded as a condition for granting the occupation of the city streets by poles and wires.

Payments to the Municipality. These conditions usually were—that the company must, in consideration of the franchise granted, agree to give the city a certain number of free arc lights; a free arc light for the city's use for each 50 or 100 arc lights supplied to commercial customers; a percentage reduction on the prevailing commercial rates for the lights required by the city, or a small annual payment per lineal foot of streets occupied for the privilege of opening the streets, pavements or sidewalks for the purpose of laying tubes, wires and conductors, and in some cases even a percentage of the gross income of the company. The latter condition was not often accepted by the companies, and the other two condi-

tions, owing to the change in the method and manner of conducting the electrical business, and also because of subsequent statutes, are at this period of no force or effect in many of the States.

A marked change has taken place, however, in the attitude of the public authorities during the past few years in the matter of granting franchises to public utility corporations occupying the city streets. Long-term franchises—50 years or more—are no longer looked upon with favor by public opinion, and there is a tendency to limit the term of new franchises to a 25-year term, or to grant, what is called under the Wisconsin statute, an "indeterminate permit," which is a franchise that continues until it expires according to law, or until the municipality in which it is operated purchases it pursuant to the statute. Substantial monetary considerations, also, are now frequently attached as conditions precedent to the granting of the franchise.

It is evident, of course, that in the end these burdens must all be borne by the consumer, and where the company can obtain its footing only under a short-term franchise it must provide in its scale of prices, in addition to a sum to provide for the specific requirements, for a fixed charge, also, sufficient to cover the rapid amortization incident to a short-term franchise. Hence the new company cannot, as a general rule, in justice to those who are expected to risk their money in the enterprise, assume to compete with a similar company not burdened with excessive conditions and enjoying a long-term franchise.

As the industry has grown and the investment therein has become larger, the municipalities have taken a more liberal attitude, from the point of view of the established companies, in the matter of granting competing franchises. The city authorities have come to recognize the undesirability of granting the right of opening the streets and erecting poles and wires, of laying ducts and cables to competing electric light companies as well as to competing gas or telephone companies, so long as the existing company renders efficient and up-to-date service at reasonable rates. This protects the investment and enables the corporation to more adequately serve the public and pursue a liberal policy of extensions into new territory. This custom has now become so well established as to be recognized as the law.

Having hastily gone over the organization of the company and its relation to the municipality, through the medium of its fran-

chise, we must pass on to other elements which must be provided for and recognized by every electricity supply company.

Taxation. Although the municipal authorities have frequently annexed burdensome conditions to the franchises, the legislatures of our various States have not allowed the public service companies to escape their attention in the matter of taxation. As has been seen, secondary franchises have been granted by municipalities with certain conditions annexed, which must be accepted by the corporation to which the franchise is granted, and which must be performed to avoid a forfeiture—such as free arc lamps to the municipality, a certain percentage of tax per running foot of underground or overhead conductors, or a certain percentage upon the gross income of the company, as may seem best to the municipal authorities.

But, in addition to these conditions, the corporation is subject to various kinds and degrees of taxation, more or less dependent upon the success of the corporation financially—as the most successful are also the most severely taxed. *First,* the real estate of the corporation is subject to the local real estate tax for city, county and States purposes, which tax, of course, varies in amount according to the extent of the real estate owned by the company and the value thereof. *Second,* the gross income of the company is assessed according to the State law in the form of a tax on the privilege of exercising its corporate franchise. This tax, of course, varies according to the amount of the income of the company so assessed. In New York State this tax is at the rate of one-half of 1 per cent on the gross earnings of the company for each year, and 3 per cent on the amount of dividends declared above 4 per cent. You will realize that this is not an inconsiderable tax to a large company. *Third,* in New York State a new tax was inaugurated in 1899 and levied on all public service corporations, called the Special Franchise Tax, under which is assessed the *"intangible right of way" or "right or permission" to do business in the streets,* which theretofore had escaped taxation. This law was said to have been passed to equalize taxation and incidentally relieve the farmer of an unjust burden, but practically it has provided more funds for State expenditures. Like all other taxes this has become a burden upon the consumer. The assessed value of special franchises has been increased yearly, and, of course, the amount collected from the corporations has been added to produc-

tion costs, and is, in the last analysis, paid by the consumer. The thing taxed is called "real estate," and this "right of way" has been assessed since 1899 with the tangible property of the corporation in the street as the "Special Franchise." In the case of an electric light company this tangible property is its conductors and subsidiary connections, cables, poles and wires in the streets, highways and public places.

This tax also varies according to the income of the company and the "use" to which the intangible right is put. It would seem inequitable and unjust to tax the ingenuity and capability of the corporate managers, which is in effect what is done, because the value of its "intangible right" increases or decreases according to the ability and business management of those who operate the company owning the particular franchise. However unjust it may seem that this form of taxation includes a tax on elements not belonging to the "intangible right" itself, it must be recognized that it is popular with the masses who ultimately pay the tax, and has taken a place among the established forms of taxation in most of our States. It is a serious question now, however, whether these special franchises belonging to regulated monopolies will in the future be of any value for taxation purposes, and whether or not this form of taxation must not be modified; because these regulated monopolies are compelled to sell their product at a price fixed by the legislature and are controlled by utility commissions in all details of their operations. *Fourth,* frequently electric light companies are also subject to taxes imposed by the terms of the franchise granted, such as I have already mentioned. These taxes, as has been stated, are sometimes in the form of a percentage of the gross or net earnings or free service of a certain number of arc lamps, or a certain amount per lineal foot of conductors or other forms of payments such as may be required by the municipality. *Fifth,* corporations in some of the States, including electric light companies, are furthermore subject to a personal property tax, which is called the capital stock tax. This tax is assessed by the local assessors and is based on the excess of the assets of a corporation over its obligations, less the assessed value of its real estate and other property exempted by the statute from taxation.

Frequently where the bond issue of a corporation is large, and the floating debt is considerable and the real estate holdings large, as well as stock in other corporations, the company escapes this

form of taxation. Very often, however, a large assessment is imposed. This tax is assessed at the same time as the taxes upon the real estate owned by the corporation and at the same rate and by the same officials.

In addition to these several forms of taxation the Federal Government has instituted what is known as the Federal Corporation Tax Law, which having been signed by President Taft on August 5, 1909, became a law and is entitled "an Act to provide revenue, equalize duties and encourage the industries of the United States and for other purposes." Under the law corporations are compelled to make returns to the Collector of Internal Revenue, and the first tax under the law included the entire year of 1909.

The sum total of these various public burdens carried by the public utility corporations in the form of taxation amounts to a very large sum, reaching in some cases to as high a figure as 10 per cent of the total income of the corporation.

Obligation to Serve. Notwithstanding all the conditions annexed to the granting of franchises and the payments to the municipalities, and the various forms of taxation to which they are subjected, there are other obligations which an electricity supply company must assume, to wit, *the obligation to serve the public.* This is an obligation which must be seriously considered by all corporations embarking in the electric light and power business, and to which adherence must be strictly given.

The granting of a franchise to a public service corporation, such as an electric company, involves a reciprocal or conditional undertaking on the part of the company receiving the franchise that it will recognize its obligation to serve the public as best it can and treat all customers similarly situated in like manner. The obligation is not only reciprocal, but it is in part payment for the provisions granted by the municipality, and it is an obligation which can be enforced at law. Most of our States have passed laws recognizing this principle, and which declare that service shall be given to all customers applying to electric companies who are within a certain lineal distance of the company's mains, under the conditions specified in the statute. An electricity supply company cannot, therefore, choose its customers as a merchant does. Once having gone into business it must serve the public, whether it wishes to or not, since under its common law obligations and under the provisions of the specific statutes its service must be given without

discrimination. In other words, the corporation must render equal service to all customers similarly situated under like circumstances and conditions, and *it may not choose* its customers.

Publicity. All of these obligations and conditions under which a lighting company is compelled to do business are imposed upon it on the theory that the public has an interest, to a certain extent, in the business conducted by the company, and is interested in its affairs and in the use of part of the property employed. This is probably because these companies are recognized as supplying public necessities and are called "*quasi*" public service corporations, because they come near to the wants and actual necessities of the people. No one at this date claims that the public utility companies can be conducted exactly as private enterprises are conducted, although not many years ago these quasi-public corporations were conducted with comparatively few restrictions on their operations, and sometimes, perhaps, without proper regard for the public interest. This situation existed where there was competition, but, of course, was more evident where the corporations had a complete monopoly.

The force of public opinion has had a great effect in bringing about a modified condition of affairs in regard to the business management of these companies. To a certain extent these corporations are really a part of the every-day existence of the people. Being a part of the public and being under obligation to serve them because of the valuable rights and privileges granted to occupy the public domain, there is sound reason, therefore, why such corporations should be compelled to consider also the interests of the public whom they serve with reasonable publicity of their affairs, so as to assure them that they are fulfilling all of the obligations which they are bound to return for the privileges which the people at large have conferred upon them, and which have enabled them to use with profit the public domain in carrying on their business.

State or Municipal Supervision

Regulation by Commission. In the early days of the Government of the United States there were no general incorporation acts, and in New York State, until nearly the middle of the last century, no general statute authorizing the incorporation of companies was in existence. *Special acts* of the legislature were passed or-

ganizing various companies and conferring franchises upon them. It was many years subsequent to this date when statutes were passed authorizing the incorporation of gas companies, which statutes were subsequently amended to include also electric light companies.

For many years after electric corporations began to spring up all over the country the policy of the various States was the "laissez faire" (let alone) policy. The managers of the corporations were allowed to carry on their business as they saw fit, without interference or regulation on the part of the State or National Government, but the aggregation of capital invested in these enterprises eventually became so large, and the possibility of the danger from the abuse of the privileges granted by the States and municipalities seemed to be so great, that the limits within which the corporations were permitted to work and conduct their activities gradually became narrower. The State extended its field of action, from time to time, over the steam and electric railroads, and finally also to the gas and electric companies. This "supervision" which has taken the place of the "let alone" action of the State is founded on the reciprocal relations of the public utility corporations and the public.

The first of the States to undertake the supervision of gas and electric companies was Massachusetts, where a statute was passed in 1885. Since that time gas and electric companies in that State have been under the supervision of the Board of Gas and Electric Commissioners, but they have not been subjected to supervision in such great detail as have similar corporations in adjacent States, nor have these companies been practically placed under the *control* of the Commissioners in the State of Massachusetts, as appears to have been the intent in other States.

In 1907 the State of Wisconsin amended its railroad law so as to include the gas and electric companies among the corporations which were to be under the supervision and control of the State. The State of New York followed its first Act of 1905 with a more complete Act in 1907, which has since been amended, and during the past year or two Indiana, New Jersey, Ohio, South Carolina, Maryland and Virginia have followed by instituting public utility commissions entrusted with more or less sweeping powers under the respective statutes. There is at the present time a considerable agitation in various States as to the advisability of passing public

service laws, so called, and a wide difference of opinion as to how far the State should go in these matters—whether its delegated officers should merely supervise the relations existing between the customers and the corporation, and see that the laws which are on the statute books are obeyed, or whether the law should be so drastic as to place not only the *supervision* but the *control,* and even what is equivalent to placing the *management* of these corporations in the hands of public service commissioners who, at least in the beginning, are untried and unskilled in the administration of these properties. There is no doubt great danger in permitting too much centralization and control by the Government, and I assume that as long as these statutes exist—and they probably will as long as the public service corporations exist—there will be a wide difference of opinion as to how far these regulatory measures adopted on the part of the State should go. It would seem that we are facing a tendency to drift away from our former simplicity in the matter of centralized government and setting aside the safe old political maxim that, at any rate under a republican form of government, the least governed people are the best governed. It does not seem right, as appears to be the tendency, where the details of business management and judgment and foresight are concerned, that the dictum of a public service commission should be supreme, or that the management of the companies should be directed by the commission, thereby depriving those who are financially interested of exercising their own judgment in the details of the business management of their own property. It is no doubt wise, on the other hand, that the State should protect the public against the evils of over-capitalization, and enforce proper relations between the company and its customers and insist upon proper treatment of the public where questions of service are involved.

There is danger from an arbitrary and too drastic enforcement of the law, as it is capable of being interpreted in a number of our States at the present time, and an abuse of the powers of supervision and control may drive away capital from investment in these corporations, so that the future may offer no inducement to the financier who has been successful in the past in obtaining the necessary capital to bring about large undertakings and important industrial expansion, because of the inducements offered for profitable investment.

If the statutes in existence at the present time had existed some few years ago, we might truthfully say that very few of our most important industrial enterprises would now be in existence. They are the result of combinations, consolidations and aggregations which have not only been successful as financial ventures for their promoters, but have given and are giving the best possible service to the public and at a low cost.

It must be admitted, of course, that there are two sides to this question—but is it not barely possible that public opinion may have forced the legislatures of our States to go too far, and must not the pendulum swing backwards again? There is a danger at the present time which may come from too much regulation and too drastic control of public utilities, the fact that these commissions are likely to alarm capital so that it will not invest in corporations of this nature, but seek investment in other channels, and that the progress of the art and industry will be retarded. I think that I may safely state, however, that the large majority of the managers of the public service corporations sincerely believe in, and will welcome, a reasonable regulative statute, which affords adequate protection alike to the general public, the consumer and to the corporation.

The public service commission of the two districts of the State of New York, appointed by Governor Hughes, have been remarkably free from political influence; the appointees, without exception, have been men of an unusually high standard, and it may be said that the decisions they have thus far rendered, and the official orders they have issued, have been, as a rule, characterized by fairness, justice and courage, and they were made with an evident desire to serve the public interest and also to treat the corporations fairly and justly. The public service commissions thus far created have served, as a matter of experience, a very useful purpose in standardizing the various practices of companies operating in the same or contiguous territories and have afforded a popular court of appeal to the public to which it might have recourse, without cost, and secure a hearing for complaints or grievances involving real or imaginary injustice suffered or discriminatory treatment received, at the hands of the corporations.

It must be said, in full justice to the New York commissions, that they have recognized broadly the general principle that where the public service corporations are effectively controlled and super-

vised by a commission they should also be protected by it in the enjoyment of their franchise rights, *and even their business monopoly,* if they render efficient service at proper and reasonable rates and treat the public with consideration and fairness.

Supervision by Municipality. During the early history of electric companies in New York State the various municipalities in which the special franchises were operated recognized the advisability that there should be some regulations concerning the operations of the companies, which were in the nature of police regulations, and which should be enforced by the municipality for the protection of life and property. These regulations in cities, generally, throughout the State were passed and enforced by the local legislative body, the common council, board of aldermen or selectmen, and in some of the larger cities they were enforced by special departments having charge of the operations of such companies in the highways and streets. In New York City the right to make and enforce these regulations was for a time vested in a special commission authorized by statute passed in the early days of the electric lighting industry.

When electricity was first used for lighting purposes in our large cities, the wires were strung on poles, the same as they are at the present time in most cases in the smaller cities and towns, or in the rural districts. In the City of New York these wires became a great menace to property, and also to life, and there was much agitation among the citizens in regard to the placing of electrical conductors underground. They were a source of great danger in case of fire, and they had multiplied to such an extent that they became very unsightly. A special Board of Commissioners was appointed by the Governor to consider the question. This board was succeeded by another board and several statutes were passed in the years 1884, 1885, 1886 and 1887, authorizing and directing that the wires be placed underground. This board promulgated numerous rules, which were in the nature of police regulations, and the power which was theretofore vested in the local authorities to make such regulations was thereafter vested in this board. Subsequently this board was merged into a city department, and that department, the Department of Water Supply, Gas and Electricity, now has the supervision of the operation of these companies throughout the streets, both underground and overhead, and all wires must be placed in accordance with the plans and regu-

lations of this particular department and the statutes referred to. Permits must be procured from the department before wires or poles can be erected or conductors placed underground, all of which is done under its supervision.

Inspection by Fire Underwriters. In addition to this form of supervision the insurance companies, in order to protect themselves, have, through the National Board of Fire Underwriters, a corporation representing and supported by the fire insurance interests, adopted certain regulations relative to the interior wiring of premises lighted by electricity and they enforce them by control over the policies of fire insurance covering the premises. All premises which are to be supplied with electricity are inspected by the representatives of the Board of Fire Underwriters, and the wiring must be placed within the building in strict accordance with the rules and regulations adopted by that body, and no current can be furnished to any prospective customer without the permit of this board first having been issued. It would seem, therefore, that the public, the customer and the company are fully protected by these forms of supervision which are carried out by the city and the insurance companies.

So much, therefore, for the supervision, regulation and control of the electric company—by the municipal authorities, the State officials, the tax officers, and the various commissions. What form of business carried on with private capital and under the guidance of experienced and capable men, such as this industry can boast of, is more subjected to government control, supervision and regulation? The affairs of these companies are indeed *not private,* as can be seen from their reports to the city, State and utility commissions, but they are, in fact, more public than the most enthusiastic believer in government control and management ever dreamed of. Notwithstanding all these restrictions surrounding the management of the business, and in spite of occasional complaints from the public, it can be fairly and justly said that these corporations are to-day conducted by persons who are actuated by a desire to give the best service at the most reasonable cost, and they are imbued with a proper sense of their full responsibility to the public by whose privilege they are permitted to exist and transact their business.

Relations with the Public

Publication of Rates. One of the first requirements which a State commission entrusted with the supervision or control of the rates of a public utility corporation considers it necessary to put into effect is the publication of its schedule of rates or tariffs.

A corporation engaged in the business of electricity supply in a community, whether regulated, supervised or controlled by a specific statute or not, has certain plain and evident responsibilities toward the public, and among these no one will question the reasonableness and propriety of the obligation to make known to the public the rates of charge which it makes to its several classes of customers, and the forms of contract under which they may contract for service. The distribution by the company of its rate schedules in pamphlet form to its consumers would seem to fulfill the conditions of publication, but a posting of tariffs in a conspicuous place in the business offices may avoid friction with the customers and eliminate any question as to whether they have been given general publicity or whether each and every consumer has been given due notice of such changes and additions, as it may be necessary to incorporate from time to time.

These rate schedules should set forth clearly and in detail the various options and privileges which are available to the public and the service conditions, as far as they may involve any obligations or responsibility on the part of the consumer or of the company.

Discrimination. Such a procedure becomes necessary, moreover, if the company desires to occupy the strongest position, should any question arise that may lead as far as the courts, involving the question of discrimination. It is a well-recognized canon of the common law that a corporation engaged in the conduct of a quasi-public business must treat all of its consumers alike, and must give each consumer the same rate it may make to any other consumer under like or substantially like conditions. It is evident that a very definite duty is imposed on the corporation, in that it must accord the same treatment *alike to all consumers* as to the cost to them of the service rendered.

It does not follow, however, that the conduct of the business of a public utility corporation engaged in the complicated undertaking of the supply of electricity for light, heat and power purposes

should be reduced to the level of a penny-in-the-slot operation, where the proper contract form adapted to each class of consumer is produced by pressing the appropriate button, as it were, and it is only right that proper and reasonable facilities which may or may not happen to appear in the contract should be extended to the individual consumer, especially when they may not in any way affect the rate or the cost of the service rendered.

In the conduct of this business involving many kinds of service contracts, wholesale and retail, with supply of lamps or without, with care of the installation or without, conditions will often arise under which a consumer desires some special attention or desires some guarantee of continuity of service; the company should be in a position to meet the wishes of the consumer, provided, always, that it is ready to accord like treatment to every other customer under like conditions, and provided no consumer receives special consideration which may in any sense reach the point of preferential treatment or undue discrimination. These are broad lines of business policy followed by every company alive to the importance of maintaining good relations with the public, and whether it is, or is not, under the supervision of a public service commission.

Complaints. As a company extends its business and broadens its field of activity, it becomes necessary to provide in its plan of organization for a complaint department. It is impracticable to make it necessary for the consumer, who may be dissatisfied with the service, with the bills, the pressure of supply, or with the lamps supplied him, to hunt up the proper department having that particular matter under its jurisdiction, or to search for the proper official charged with the duty of surveillance of that branch of the service. A well-organized complaint department, where the consumer will receive courteous consideration, and where he is received by alert and patient clerks, who at least for the time being will take his view of the case, will be found to assist greatly in the development of that great asset of every company, the goodwill of the public. But it is not only in the lodging of the complaint that the customer receives his impression of the company's business methods, but in the promptitude with which his complaint is investigated, and the form in which the findings are transmitted to him. In case the company is found to be at fault, which will occasionally happen in all large and complex business organiza-

tions, a prompt acknowledgment of the error of omission or commission will go far toward mollifying the irate complainant. It should be continually held before the employees that it is their *duty* to serve the public and to see that it is *well served,* and to realize that the customer who presents a proper complaint is in that way actually rendering the company a service, since it enables the management to apply the necessary remedies and strengthen the weak links.

Branch Offices. With the wide range of territory which the rapidly expanding companies cover, it is impossible to conduct all of the business at one central point, and it soon becomes necessary to establish local or branch offices. It is an unsettled question in corporation economics as to how far it is wise to go in the assignment of activities to be centered at the branch office, and how far to go in the direction of rendering the local office autonomous. Much will depend, of course, on the character of the territory it is proposed to serve, and whether it is merely a district or ward of a great city, or one of a number of small towns or villages supplied as a distributing center from a common generating plant.

A village or small town will expect to have a special local representative assigned to it, and the central administration will see to it that the little community will feel that its growing importance is recognized, and that its public can have all but its most important questions handled locally and without transmission to the distant headquarters.

The branch offices in the divisions of a large city need not necessarily be equipped for the conduct of such a wide range of business, and their activities are usually confined to the acceptance of applications for service and payment of bills. As the office grows it is soon found necessary, however, to extend its activities and to afford place for local inspectors, and then follow in due course local show rooms, store rooms, repair headquarters, etc.

In the early days of the electric lighting industry it was necessary for the central station to engage in many activities which have now been left, in many cases, to independent enterprise. It was necessary for the station to undertake the wiring of premises, the supply of lighting fixtures, the rental and sale of motors and other branches which are in these days left to wiring contractors, supply houses and manufacturers' agents.

The wiring of houses, stores and business buildings had formerly

to be done by workmen—admittedly not always experts—who were a combination of mason, plumber and carpenter, and this material had to be utilized by the central station companies to wire the consumer's premises.

Wiring Inspection. As the art advanced the skilled wireman was developed, as well as the more generally skilled artisan known as the electrical worker, and the central station soon found itself in a position to leave this branch of work entirely in the hands of the electrical contractors, and devote all of its energies to the lighting and power business. While it was practicable to formulate rules and make specifications with which the installations must comply before being connected to the company's supply mains (and these were as necessary a protection to the prospective lighting customer as they were to the company), and to prevent one customer from causing disturbances which might possibly interfere with the service to others, it was found that it was still necessary for the company to make a final inspection of the customer's wiring before the service was connected.

Wiring inspection by the company has been rendered almost superfluous by the excellent rules, and particularly by the National Code formulated by the Board of Fire Underwriters in co-operation with committees from the national technical societies, and by the inspections made under the auspices of the Fire Underwriters. It is still necessary, however, to cover by company inspection such other important details as the balancing of the load on the two legs of the three-wire system, the inrush current of motors, power factor of translating devices, etc.

It is highly desirable that the companies assume no responsibility for the customers wiring installations, either in connection with the first installation or for subsequent maintenance and repairs. The ideal condition to be reached is to have the electric lighting company as free from responsibility for the interior wiring on customer's premises as the gas companies are free from assuming any care of the consumer's interior gas piping.

It must be admitted, however, that it is important for the progress of the electric lighting company that its customers shall be able to get their premises wired conveniently, safely and economically, and they will not hesitate to look after this work themselves if they feel that the public is not efficiently served by the local wiring contractors.

While the station should avoid assuming responsibility for the consumer's wiring, it must be ready to answer promptly the customer's call for emergency repairs. All companies have repair men on hand day and night to respond to telephone calls to replace burned-out safety fuses, make temporary repairs in case of grounds and short-circuits, and do whatever may be necessary to promptly re-establish the customer's service, at least as a temporary repair; the complete repair to be made by his own wiring contractor.

It is owing to the very close and efficient co-operation of the Board of Fire Underwriters and electrical contractors with the central station companies that the present high standard of electrical service has been attained.

Supervision of Lamp Installation. It is generally appreciated that the key to success of the electric lighting industry in this country is the general supervision and control exercised by the central stations in the matter of the supply of incandescent lamps to the customers.

The practice of including in the price of current to the consumer a liberal supply of incandescent lamps without extra charge has always been an important feature of the policy of the larger stations. It was largely followed also in the smaller communities. The establishment of this policy was probably due in a large measure to the fact that in the early days of the industry the local companies, usually licensees of the large manufacturing companies, controlled the sale of lamps in their respective territories, the companies early recognizing the fact that the success of the electric lighting business was absolutely dependent upon the quality and service given by the incandescent lamps, and it was fatal to the business to have poor lamps get into the hands of the consumer.

The incandescent lamp is a difficult product to manufacture in uniform quality, and it is not to be expected that the average customer should possess sufficient knowledge and experience to enable him to purchase wisely a product of whose quality it is so difficult to judge. While tests made at the moment of purchase may reveal some of the characteristics of the lamps, yet it is practically impossible to obtain any knowledge of the true value of an incandescent lamp without making a careful test covering practically the whole life of the lamp. Such tests it is quite impracticable for the consumer to make, and he is therefore at the mercy of those selling cheap and unsatisfactory lamps of poor

efficiency, poor selection of voltage, depreciating candle-power and short life. A customer furnished with such lamps would soon be dissatisfied with electric lighting, probably attributing his troubles, in part, at least, to defective service of the lighting company.

In Europe the practice is general not to include the free supply of renewal lamps with the cost of the current and the customer purchases his lamps in the open market. He is very likely to consider the *life* of the lamps *the* important feature of their quality, obtaining long life at a sacrifice of either efficiency or candle-power, or purchasing lamps marked for his voltage, but which are really *marked up* by the manufacturer several volts above the proper rating. The result is a long life, perhaps, but excessive bills and poor light. If left to his own devices the customer would purchase 3.5-watt lamps, because they would give a long life, which is the factor that makes immediate appeal to his pocket, when at the price he may be paying for current he is wasting the price of three or four lamps in excessive current consumption. The central stations have quite generally pursued the policy of supplying their customers only with lamps of the highest efficiency, and as companies usually purchase their lamps under close specifications as to voltage, rating and efficiency, and in very large quantities, they are able to procure them at a favorable price, and can, therefore, afford to supply the public with the very best lamps, and are enabled to include in the price for current only a very moderate charge for their renewal. The result has been a very high standard of lighting with lamps uniform in candle-power, of high efficiency, and with a good life. In European countries the result is most unsatisfactory and the customer's circuits are found to be loaded up with very inefficient lamps giving rise to continued complaints of high bills. It is in this practice of supplying free renewals of incandescent lamps that the large central stations differ most from European practice, and in this particular our American companies' policy has much to commend it, in fact it is believed that it is largely responsible for the rapid extension of the electric lighting business in our large cities. With the advent of the higher efficiency metallic filaments, such as the tantalum and tungsten lamps, it was impracticable to include the free renewal of these high-priced lamps in the cost of current, and it has made the preservation of high standards of uniformity increasingly difficult, and while not so manifest in the candle-power of

the individual lamps, it is at least apparent in their lack of uniformity of voltage rating and efficiency. In the endeavor to still preserve in a measure the control of the high lighting standards, the larger stations have followed the policy of supplying the metal filament lamps on payment by the consumer of the difference in cost between the renewal cost to the company of the carbon lamps and the price of metal filament lamps.

Lamp Deliveries. In applying the free renewal lamp policy the companies have, as a rule, furnished renewals very freely, exchanging without question any lamps that have become dim or depreciated in candle-power, and they have in most cases established lamp deliveries to the consumer's premises at regular intervals in addition to effecting the exchange of lamps at the companies' local storerooms.

With the prevailing prices for current very considerable savings are possible to the public by the use of tantalum and tungsten lamps, but where the lamps are burned under conditions of only occasional use, or where the cost of current is very low, high-priced lamps of the highest efficiency may not be the most economical in the end.

This supervising care of the customer's lighting units by the station may savor of paternalism, and may be a radical departure from the attitude of the gas companies toward the consumer's equipment, yet the uniformly satisfactory results to the public and to the electric lighting companies fully justify the policy.

Emergency Repair Service. It is necessary to provide at the customer's service and in the installations safeguards against defective insulation, short-circuits and overloading of circuits by installing safety fuses and cut-outs with fusible strips or wires.

When these, on occasion, burn out the customer's lighting service is seriously impaired, and in order to restore the service as promptly as possible the stations keep on hand, day and night, at convenient local points, repair men or emergency employees ready to respond instantly to any calls.

This service the company performs to avoid inconvenience to the public and to restore the customer's service without loss of time, and without the necessity of hunting up the local electrician or electrical contractor. The repairs may be only of a temporary nature, until the electrical contractor at his convenience may make them permanent, but it is a service appreciated by the consumer,

and it has made possible the equipment of the most important electric lighting installations without any other auxiliary or reserve equipment.

Billing. In another place consideration will be given to the methods of charge for current, and we will refer here briefly to the rendering of bills to the consumer. These are mailed to the consumer or presented by a personal call from a collector. The bills usually give the readings of the supply meters at the beginning and the end of the period they cover, with the difference in the readings so that the customer may himself check the readings and verify the accuracy of the bill. It is unfortunately true that more than one visit is often necessary to collect the bill, and it is sometimes necessary even to disconnect the service when payment of the bills cannot be secured.

The matter of the credit standing of consumers and the requirement of making guarantee deposits is also important, and while it is the general practice to require deposits from consumers whose credit is not well established, they are usually allowed interest on the deposits at the legal rate.

It is in these matters that the relations between the company and the public are put to the most severe test, and it is necessary to carefully follow a liberal but well-defined policy, avoiding, on the one hand, the danger to the company of accumulating uncollectible accounts, or, on the other hand, of appearing to the public harsh and arbitrary in its methods.

Relations with Employees

The relations of the company to its employees are secondary in importance only to its relations with the public, and it is well nigh impossible for a public utility company to maintain the good-will of the public, if it has not the loyal support and co-operation of its employees, with whom the public comes in direct contact, and from whom it gets its impressions of the company.

But I must not forget to commend also the loyal construction forces and the faithful band of operating men *who are not seen of the public*—BUT BY THEIR WORKS—and who labor without praise and without glory, like the Scotch Engineer McAndrew, of whom Kipling has sung.

In no industry is the loyal co-operation of its employees so necessary to the success of the corporation as in the electric lighting

industry, for in no industry are the little details of so much importance, and negligence or careless service capable of doing such serious damage.

Welfare Work. It is also true that no industry is served by a more enthusiastic, loyal and faithful body of workers. The workmen engaged in the electric lighting industry are, as a rule, young men, ambitious to learn and with a desire for improvement and advancement; they are, therefore, interested in all forms of welfare work, particularly in the various forms of educational activity. The central station companies have always been leaders in the movements for improving the conditions of the workers, and in furthering every progressive endeavor which will improve the relations with their employees.

All of the larger companies have employees' meeting and club rooms, libraries and reading rooms, athletic and social associations, and mutual benefit organizations of various kinds among their employees. Many of the companies have organized lecture courses for their employees, presenting technical subjects directly related to their work, or laboratory courses where it is possible to become familiar with the handling of electrical instruments and the making of the simpler tests. Many of the lighting companies' employees have enjoyed educational advantages beyond the public school curriculum, and others have followed correspondence school, night school or trade school courses, but all have opportunity through the various forms of welfare work conducted by the central station companies of increasing their knowledge of the industry and of increasing their value to the companies.

Workmen's Compensation. In line with these various welfare activities the companies have been most successful in adjusting directly with their employees claims for accidents growing out of their employment, and only in very few cases has it been necessary for them to have recourse to the slow processes of the courts.

It has, therefore, been possible for the companies to readily adjust themselves to the requirements of any legislative enactments providing for workmen's compensation, and in some cases they have been able, through their experience in these matters, to give valuable assistance in shaping legislation.

In addition to the usual hazards incident to the conduct of the industries involving the use of machinery, our industry has certain *peculiar* risks growing out of the character of the production and

distributing apparatus which it employs. It is a matter of experience with the companies that many of these accidents, some of them, unfortunately fatal, are due to the lack of proper precaution and care, or over familiarity amounting often to carelessness and negligence.

"**Personal Equation.**" The "personal equation" and "human element" enters largely as a contributing factor in these accidents, and they often involve others besides the principal; errors made in mistaking a live circuit for a dead one, in selecting the wrong switch or cutting the wrong cable, are often responsible for serious and fatal accidents.

In spite of every precaution and the exercise of every care, these accidents will happen, but no company has yet done too much in the direction of avoiding them or exhausted all the possibilities of preventive measures.

Operating Rules. One of the means taken by the larger companies to reduce accidents is by the formulation of a comprehensive code of operating rules in which provision is made for possible errors in human judgment, where mistakes are rendered less likely by having two minds at work instead of one, where written instructions take the place of oral orders.

As the transmission and distributing systems expand and cover larger and larger areas, as the voltages increase and apparatus becomes more complex and varied in character, it becomes absolutely necessary to lay down certain fundamental rules for the guidance of employees, and while it is impossible to so safeguard all operations as to make errors or mistakes impossible, they must, in any case, have the moral effect of increasing precaution and making each employee feel a sense of responsibility in these matters towards his fellow workers.

Sick Benefit Funds. But it is *not* only a protection against accident that the worker needs for himself and his family, but also against the possibility of sickness and impaired efficiency.

Protection to the worker against sickness may not be provided by the State or as a legal obligation on the employer for many years, but the public utility companies should see to it *now* that their employees have such protection through the organization of sick benefit funds and free medical service to which the companies should be liberal contributors, considering such contributions as a legitimate part of their operating expenses.

Pensions. The industry is of too recent creation for any considerable part of its workers to have reached an age when their usefulness and efficiency has become seriously impaired, and when they must consider laying down their burdens. Such is the case, however, in many other industries, and the time is ripe for the serious consideration of this problem. Germany, Great Britain and France have all enacted legislation which, in various ways, affords at least a partial solution of this serious problem in sociology, and it behooves our flourishing industries to take hold of this problem and press for a solution. This problem will not wait for solution on so broad a basis as action by the Federal Government would involve, and, paving the way for such more general governmental action in the future, the large and prosperous enterprises of our country should lead the way and make liberal provision for taking care of their disabled and superannuated workers. Something is already being done by a few of the great industrial corporations, notably some of the railroads, but they represent only isolated exceptions to the general rule of making no provision for the worn-out and now unproductive employee.

Profit Sharing. But it is *not* only a provision for the dead or disabled worker to which the forward movement for the betterment of the condition of the working classes aspires; it is some participation, however small, in the good things of life while they are alive, some little latitude which will enable them to emancipate themselves from the constant struggle for a mere existence, some provision for an education for their children, which they desire, and the enjoyment of some of the modest comforts which a continually advancing civilization provides. That it is possible to accomplish something in the direction of removing such movement for the improvement of the condition of industrial workers from the sphere of Utopian dreams or socialistic aspirations, is shown by the recent action of some of our largest employers of labor who have already adopted, or who are considering adopting, some form of profit sharing or savings investment for their employees.

Such a movement should signally appeal to the large public utility corporations for it is they who would profit most by the kind of co-partnership arrangement between capital and labor which some such plan would establish.

It is already recognized that it is part of a wise policy for large corporations to offer inducements to their employees to become

investors in their securities and place the savings of their employees on a participating basis with their stockholders.

It is hardly to be expected that such a co-operative relation between capital and labor and between the company and its employees, will solve all labor questions, but it will undoubtedly ameliorate the condition of the worker, incite him to thrift, contribute towards his uplift and make him feel that *his interests* are also the interests of the corporation, and vice versa.

Relations of Employees to the Public. One of the aims of the management of a public service corporation is to establish an "esprit de corps" among its employees, such that they will feel it an honor to be a part of it, and be enthusiastic in co-operating with their fellow workers in maintaining a high standard of service efficiency, and in securing for their company the good will of the public. In order to secure this much desired end, it is necessary to allow no opportunity to pass by for impressing upon the employees the necessity for treating the public with courtesy and consideration, making clear to them the peculiar relation which they bear to the company's customers and to the public as quasi-public servants. The attitude which the representative of the company takes toward a complainant, and the attention which is given to any cause for dissatisfaction with the service and the thoroughness of the investigation, will largely determine the standing of the company in the public view and determine the value of that precious, though intangible, asset of a public utility corporation—its good-will.

It is interesting to note the pleasure with which the employees regard the characteristic pin or button of the popular company, and their desire to wear it in a conspicuous place, regarding it not as a badge of servitude, but as a badge of honor.

Relations with Organized Labor. Such a relationship will go far toward solving the vexing and troublesome problems which arise in regard to relations with organized labor in the form of labor unions and trade organizations.

Where the whole or a part of the employees are organized as a union, it is well to impress upon them by a wise but determined policy that the company will expect them to hold its interests above that of the organization, and that loyalty to its service must be the unvarying attitude of its employees. Where such organization becomes effective it is just as well to recognize the fact and establish good relations with it, considering it as one of the modern

forms of co-operation and a proper form of combination as long as its attitude does not overstep proper limits or undertake to dictate to the management how it shall conduct its business.

The relations with organized labor give rise to some of the most difficult questions with which the industrial enterprise has to deal, and calls for the exercise, by the executive officers, of patience, justice and determination, all at the same time.

Service Conditions

In order to provide for meeting the continually augmenting demands for service made on the central station, it is necessary to give consideration from time to time to increases of equipment and adequate provision must be made to take care of the load in the generating and converting stations, as well as in the transmission and distributing system. This provision must be made several years ahead of the actual requirements, for the large types of power stations now necessary cannot be designed and erected in less than 2 years' time, and 3 years is none too liberal a time-allowance when land must be purchased, dockage and coaling facilities secured, rights of way obtained, plans drawn and contracts let all in advance of the actual work of construction.

When conditions are normal with no unusual disturbing factors such as a period of business depression, or some radical change in the state of the art as, for instance, the introduction of high efficiency lamps, it is possible to predict the requirements from year to year with almost mathematical certainty and with close approximation in advance for 5-year periods.

Extensions. The absorption of other interests or extension into new territory will also disturb the ordinary rate of increase, and these, too, must be provided for. It has already been pointed out that the law under which the company is organized lays upon it the obligation to connect any customer applying for service when located within 100 feet of its mains. Extensions of a greater distance are optional with the company, and are usually provided for in accordance with a general plan of extension or made in any specific case by considering the probable annual return from the service as compared with the cost of making the extension.

It is the general practice to make these extensions beyond the 100-foot limit, when the estimated return will cover the cost

of construction within a reasonable time, say in 1, 2 or 3 years, the return being figured on the average for the particular class of business based on the company's experience.

Underground Service. Where the extension is made to an underground system the new investment required is, of course, much greater than in the case of an overhead system, and extension into an undeveloped territory can therefore be undertaken with greater liberality in the latter case than in the former. It must also be borne in mind that where an underground extension is necessary the large proportionate cost of excavation and repaving makes it desirable to provide in advance for reasonable future requirements at a considerable immediate cost for ducts and manholes; whereas, in the overhead construction sufficient flexibility is secured by the character of the construction without special provision for reasonable additions to the line capacity and without heavy expense. These considerations make it clear why it is possible to develop a new territory much more readily with an overhead system, and why the company hesitates to place its wires underground until the density of distribution has reached a certain value, or the character of the territory makes it imperative for other reasons. The preference of the public and of the authorities is, of course, for underground construction, and it is good business policy to meet the public demands where practicable, but it is not always possible to do so on account of the very high cost of underground construction and its lack of flexibility.

It is often necessary, however, to face the larger outlay rather than turn down the business and leave the territory undeveloped, particularly in view of the increasing difficulty of obtaining permits to set poles where the consents of property owners are required, as is often the case under the municipal ordinances or State laws. It is, of course, admitted that service from an underground system is subject to less disturbance with a lesser maintenance cost than an overhead system, but the first cost is much higher.

A. C. and D. C. Supply. It was not so very long ago that a large part of the time of the meetings of electro-technical societies was taken up with interminable discussion of the relative advantages and disadvantages of the direct-current and alternating-current systems of distribution. These questions are no longer the subject of heated discussion and debate, as time has gradually succeeded in

bringing about the logical solution of the problem, and both systems are now usually developed side by side, not, perhaps, in the same territory, but under the auspices of the same company, that system being chosen which is best adapted to the territory, having in view its immediate and its future requirements. With the vast improvement that has taken place in transformers within the last decade, and in alternating-current motors, the service is very unusual which cannot with equal facility be taken care of by direct- or by alternating-current distribution, and in view of the flexibility of the alternating-current system in providing easily and efficiently step-up or step-down voltages, it has the field quite to itself in the less populated communities, and is usually adopted for the outlying districts of the larger systems, and only the districts of comparatively high density are developed with direct-current service.

The development of rotary converters and transformers of very large capacity and of high efficiency, and particularly of high-tension transmission with underground cables, have made it possible to make considerable extensions to existing direct-current systems, and in the centers of the larger cities electric service is now usually available in every street, and this is largely true of the outlying districts, the suburbs being supplied from alternating circuits and distant communities by high-tension transmission circuits.

Lighting. The multitude of electric illuminants made available by the rapid progress in the art give a wide range of choice in efficiencies, size of units, color values and distributing power. In all three of these characteristics the advances made in the art within the last few years have been equally striking, and improvements are in the order of each day.

A business organization forwards its material interests when it sets and conforms to a high standard of service, and this is particularly true of an electric lighting company.

Quite aside, however, from the purely material benefits which, with this end in view, obviously dictate a liberal policy, it must be remembered that improvements in service by a central station company, even though apparently slight in character, affect a community so generally that the aggregate benefit to the cause of improved illumination is very large.

Improvements in pressure regulation, assured continuity of service, increased efficiency of lamps, proper attention to reflectors

and globes for the protection of eyes against excessively brilliant light sources, and for the better distribution of the light, even though elements of activity which find their motives in the ordinary approved commercial policy, are strong factors in the advancement of the illuminating engineering cause.

A truly wonderful advance has been made in the standard and in the quality of illumination obtaining in our stores, business offices and our homes, due to the introduction of the tungsten lamps and with the efficient and pleasing appliances for diffusing and distributing the light, we have arrived at a point where radical improvement seems well nigh impossible.

To make the most efficient and most effective application of these various developments requires specialized skill and wide experience, and it is a most timely movement that has been happily initiated by this great seat of learning in its organization of this course of lectures on Illuminating Engineering, under the auspices of the Illuminating Engineering Society.

Street Lighting. In the open arc lamp the electricity supply corporations were early in possession of a cheap and effective means for lighting the public streets and large areas, open or enclosed.

In the fitful glare of these lamps, uncertain in quantity and quality, it must be admitted, many arc light companies had a source of income, steady and substantial, which laid the foundations of their prosperity and made possible their advance into other fields in which the business, and apparatus for conducting it, was more flexible and the opportunities for expansion much broader.

The change that was wrought by the introduction of the enclosed arc lamp was a serious indictment of the older type, for the newcomer was, in comparison, sadly inefficient, but it had the advantage of steadiness which was not a conspicuous characteristic of the open series type, and it notably reduced expense in maintenance.

In Europe these characteristics did not give it a footing, for the European types of open arc lamps were reasonably steady with the superior cored carbons, and labor is, or was, much cheaper than with us, the result being that the enclosed arc lamp received very slight appreciation of application on the Continent. With the advent of the flame arc lamps and metallic electrode lamps, the arc lamp has obtained a new lease of life, at any rate as regards its application to street illumination. That some of these types secure their high efficiency—considering efficiency in its purely tech-

nical sense of candle-power per watt—at a sacrifice of beauty and aesthetic effect, is unfortunately true, and it is likely that the more flagrant violators of modesty and unobtrusiveness will be relegated to places where mere intensity of illumination is the only desideratum.

The enclosed arc lamp, in addition to its other advantages, contributed notably to the improvement of light distribution in our street illumination, and really secured for electric street lighting a permanent place removed from mere show or display effects.

In this direction it paved the way for the introduction of incandescent electric street lighting which was made possible by the development of the tungsten lamp, the Welsbach lamp having put the carbon incandescent lamp out of the race as far as street lighting was concerned.

The electric lighting companies have not yet reaped the full benefit of the possibilities presented by this field, and they have been rather dilatory in pressing the advantages the new lamp gave them in opening up this field to electricity supply.

Power Service. While the subject of electric power service is somewhat foreign to the field covered by these lectures, yet the dependence of the electric light companies on their power business is so great and their progress is so intimately concerned with the applications of the electric current to industrial power that it is impossible not to say a few words on this subject. The electric motor, as a source of power, occupies a field all to itself; its reliability, efficiency and convenience are so far in advance of any other method of supplying energy to moving machinery that the central stations have in it a field of application for their output, giving large returns at remunerative rates and affording on the whole the largest measure of satisfaction to the consumer.

Heating. The application of electricity to heating purposes presents a most attractive field, and need only be referred to here owing to its economic relations to our subject.

The sales of electric current made by the central station for heating purposes are, as yet, modest, indeed, but this application has proved such a great convenience in the household and is so much appreciated by the public that it undoubtedly gives a great stimulus to the introduction of electric service into the house.

The convenience of the smoothing iron, curling iron, toaster, chafing dish and other household utensils ably flanked by the use-

fulness of the electric motors as applied to the washing machine and vacuum cleaner, make electric service in the house simply indispensable, quite apart from its applications to lighting. The larger commercial applications of electric heating have yet to be developed, and the prospect here is not so bright as in other directions, although considerable applications have been made in industrial processes and in certain manufacturing, including the bookbinding, hat and laundry industries.

Storage Battery Charging. The supply of current for the purpose of charging storage batteries for commercial and pleasure vehicles promises to develop into considerable proportions serving to further popularize central station supply. With the notable improvements in lead batteries and the introduction of *new types*, making the batteries more dependable, less liable to destruction, more robust and capable of being handled by other than skilled experts, and particularly with a greatly increased life, there should develop a large field for their usefulness.

With high capacity types it is practicable to secure a sufficient radius of action for the pleasure vehicle to make it available for all but extensive tours, and the commercial vehicle for trucking and delivery purposes should ultimately largely replace the horse and wagon in all our large cities. The progressive central stations are doing much to encourage this business by providing charging stations scattered over the territories where on emergency the vehicle may obtain at least sufficient current to get back home, and in some cases the companies assume maintenance of the vehicle as well as the battery to stimulate its introduction.

Continuity of Service. The one factor upon which the commercial success of a public service company most depends is continuity of service. No central station can assume to provide completely for all the electricity required by large communities and over extended territories for important industrial and manufacturing and traction purposes, as well as the requirements of the home and the store, unless the service is rendered reliable and dependable.

The large companies have most enviable records in this particular, and they have exhausted every possible provision which skill, experience and a liberal provision of capital can provide in order to secure this most important desideratum. The supply of current for traction purposes, for the vertical transportation of

the public by electric elevators in the tall office building, the electric drive of factory and workshop, and the lighting of theaters, auditoriums and public buildings where vast crowds congregate, require a regularity and constancy of service which exceeds the necessities of the residence or the shop. In order to secure the general application of electric service to old buildings, as well as the newly constructed, it is necessary to provide electric wiring of moderate cost, and if it is not necessary to give any thought to the provision of an alternative system of illumination to provide against failure of the electric service, then the wiring for electricity is not handicapped by the necessity of such additional outlay. It is necessary to maintain a high standard of service to obtain the important business that might otherwise go to isolated plants, which, providing usually for large blocks of business, represents large output which it is absolutely necessary for the central station to secure. Continuity of service is secured by liberal provision of reserve capacity usually located in several power houses with tie connections, so that they may assist or even substitute one another in case of need, duplicate high-tension transmission and feeder lines following different routes, substations distributed over the territory at the important nuclei of consumption, and where direct-current supply is concerned, provided with adequate storage battery capacity and a well-meshed distributing system securing the customers supply from a secondary network feeding the customer from more than one direction. The modern types of power station and substation apparatus have large overload capacities, and with equipment of the necessary flexibility, provision is made for all ordinary contingencies. The huge concentration of power in our largest power stations with units of 20,000 kilowatts, and large capacities of generating apparatus, all operating in multiple, and with the enormous instantaneous capacity for giving out power supplied by the fly-wheel effects of rotary converters and motor generator sets, the problem of providing against every possible contingency becomes more complex, but the manufacturers, designers and the engineering staffs of the companies have succeeded in mastering the problem.

Voltage Regulation. It is not enough, however, to provide merely for continuity of service to satisfy the high standard requirements of the central station service of to-day, since the current must be supplied also at constant voltage. In this respect

also there has been marked progress, and the adequately equipped, well-managed and carefully operated stations experience no difficulty on this score. The delicacy of the filaments of our incandescent lamps (notably less sensitive to fluctuations in voltage are the new types of metallic filament lamps than the old carbon lamps) require a fairly constant pressure to be maintained, else we have poor light, lack of brilliancy and dissatisfaction on the part of the consumer on the one hand, or poor life of lamps, depreciation in candle-power and excessive bills on the other.

Adequate Equipment in Stations. The state of the art provides modern substation equipment of sufficient reliability and flexibility to satisfy the most exacting requirements, and the ability to render perfect service resolves itself into the dependability on human nature and the reliability of the employee, backed by the ever-ready storage battery always connected to the bus-bars, and able to furnish current instantly to the limit of its capacity.

"**Human Element.**" It is a fact, however, that notwithstanding every possible care and attention, and every safeguard and check with which the operations depending upon the "human element" in the service are surrounded, a considerable number of derangements of the service are attributable to the failure of the human element to properly perform its functions.

Yet notwithstanding these small failures to operate properly on the part of links in the system, animate and inanimate (and these small failures referred to are usually of a character that do not affect the consumer and pass unnoticed by him), the standard of central station service is very high—it compares most favorably with the service rendered by other comparable industries, and is giving undoubted satisfaction to the public.

Accounting—Operating Costs and Fixed Charges

The development of a suitable accounting system to record the diverse and manifold business activities of a modern public utility corporation has been the work of years of experience and careful thought.

In a corporation the owners or stockholders themselves rarely engage actively in the conduct of its affairs, which are usually carried on by the directors and officers acting, as it were, as trustees. The directors must periodically account to the stockholders or the owners as to the conduct of their stewardship, and their report

must set forth with exactness the essential facts. The records, therefore, must be of such a character as to show the transactions in detail and be also of a permanent nature, so that the facts can be determined at any future time. Such records constitute accounting in the full sense of the term. An electric lighting and power company shares in this common obligation of the corporate form of organization, but as it is a public service corporation operating under a franchise granted by the State or municipal authorities with the privilege of using the public highways in the public conduct of its business, it has special obligations to the State and to the public, and is compelled to record its transactions in accordance with regulations promulgated by the supervising authorities. The operations of a modern public utility corporation frequently extend over an area of 100 square miles, or more, and employ, in their various capacities, thousands of employees; it is necessary for the management to keep in direct touch with all the various transactions, widely separated by character and locality, and it is enabled to accomplish this through its system of accounts. These accounts, in addition to containing the necessary information, must present the essential facts in a condensed form, yet so as to bring out the more important details in a clear and striking manner.

N. E. L. A. "Accounting System." It has long been the aim of the national associations representing the more important public utilities, steam railroads, street railways, gas and electric light, to standardize their respective systems of accounting so that each company operating the same utility might keep its accounts on the same general scheme, enabling rapid examinations and comparisons to be made. In conformity with this concept the National Electric Light Association, representing the central station industry of the country has adopted and published a uniform system of accounts which fulfills all the necessary requirements. It is not possible to attempt here a lengthy description of this system, or of its details, and a glance at the main accounts must suffice (summary headings only are here given), providing for construction and operating disbursements.

CLASSIFICATION OF ACCOUNTS

Construction and Equipment

DIVISION	SUBDIVISION.
1. Organization.	
2. Royalties, franchises and licenses.	
3. Generating plant—steam........	Land.
	Structure.
	Boiler plant.
	Prime movers.
	Electrical plant.
	Miscellaneous.
4. Generating plant—hydraulic	Land.
	Structure.
	Dams, canal and pipe lines.
	Turbines and water wheels.
	Electrical plant.
	Miscellaneous.
5. Generating plant—gas	Land.
	Structure.
	Gas producers and accessories.
	Gas engines.
	Electrical plant.
	Miscellaneous.
6. Underground conduits.	
7. Poles and fixtures.	
8. Transmission	Conductors—overhead, underground.
	Land.
	Structure.
	Substation equipment.
9. Storage batteries.	
10. Distribution	Overhead conductors and devices.
	Underground conductors.
	Services.
	Meters and line transformers.
11. Arc and glower lamps.	
12. Customers' installation.	
13. Municipal street lighting system.	
14. General office and branches......	Land.
	Structure.
	Furniture and fixtures.
15. Other equipment	Land.
	Structure.
	Coal storage equipment.
	Shop equipment.
	Storeroom equipment.
	Stable equipment.
	Laboratory equipment.
	Tools and instruments.

16. Miscellaneous—during construction	Engineering and superintendence.
	Law expenditures.
	Taxes.
	Interest.
	Injuries.
	General.

CLASSIFICATION OF EXPENSE ACCOUNTS

Operating Accounts

CLASSIFICATION	SCOPE
1. Production	Cost of electric current delivered to station terminal board.
2. Transmission	Cost of conducting current to substations and cost as delivered to distribution system.
3. Storage battery	Cost of storage.
4. Distribution	Cost of conducting electric current from substation terminal board to customers' premises and including repairs to electrical meters.
5. Utilization	Cost in customers' premises, including first installation and renewal of incandescent lamps, trimming arc lamps and incidental repairs.
6. Commercial expense.	All office expenses in connection with customers' accounts.
7. New business	Cost of securing new business.
8. General	Administration and miscellaneous.

It should be understood that each of these classification heads in turn includes many distinct and clearly specified subdivisions representing the various elements which go to make up the several important elements of which it is a summary. For instance, under Production these separate items are as follows:

PRODUCTION EXPENSE

Production	Amt.	Cents K.W.Hr.	Production Repairs	Amt.	Cents K.W.Hr.
Station sundries			Sundries		
Supt'ce and care............			Boilers..................		
Boiler labor			Piping..................		
Engine labor			Engines		
Dynamo labor................			Mechan. apparatus....		
Total labor			Dynamos...............		
Water (incl. boiler comp.)..			Elect. apparatus.......		
Fuel (incl. removing ashes)			Station structure......		
Lubric., waste and pack....			Tools and implements		
Total..................			Total		
Grand total—Production..					

Subdivisions are specified for each of the other eight classification heads, giving the important items under each. It is impossible to present these in detail, but the above example shows the general features of the scheme.

Analysis of Revenue. In compiling monthly expense statements in accordance with the foregoing schedule, there is also included a statement of the kilowatt-hours sold, and each item of cost is reduced to the corresponding cost per unit of product sold; the statement disclosing at a glance the actual conditions. In order to facilitate comparisons with previous periods, it is customary to present the statement in a comparative form, that is to say, showing in parallel columns the expenses for a given month compared with those of the previous month of the same year, or the corresponding month in the previous year.

As with the expenses, so also with the revenues of the corporation. It is not sufficient to know that the monthly income amounted to a certain figure, the important items must also appear. The quantity of electrical energy supplied, the rate classification under which it is sold, must all find a place in the modern accounting exhibit. Thus the management will receive a monthly statement containing income statistics arranged somewhat as follows:

Form of Contract under which Current is Sold	K. W. Hrs. Sold	Amount in Dollars	Per cent. of Total Sales	Income per K. W. Hr.
Retail rate....................				
Wholesale rate................				
Power rate....................				
Municipal street lighting....				
" building lighting.				
" building power...				
Other elec. corp...............				
Railway service...............				
Miscellaneous.................				
Total sales of current........				

We have already shown how the unit cost per kilowatt-hour sold is accounted for, and we now have for comparison therewith the income per kilowatt-hour sold, and it is only necessary to add that the difference between these two figures is the operating profit per unit per kilowatt-hour sold.

Depreciation. There are two kinds of depreciation, namely, depreciation ("wear and tear") and supercessional depreciation. Depreciation arising from use or wear and tear is a reasonably well-known factor, and life tables exist which give fairly closely

the annual rate as approved by recognized authorities, to be applied for buildings, generating and distributing apparatus. Supercessional depreciation, however, is entirely a matter of judgment and conjecture. Increase in the business and improvements in the machinery and devices used in the business require the discarding of old apparatus still in good working condition, the limit of whose useful life has not been reached. Nevertheless, depreciation is a fact and must be treated in all financial exhibits before the true status of affairs can be known, the allowance to be made for this purpose must therefore be estimated. The charge for depreciation cannot be distributed over the items in the operating schedule, and the amount set aside for this purpose must be deducted in one item from the net profit. The amount of the depreciation is not an expenditure of cash made during the period involved, but is a reserve, and it should therefore be treated separately and independently in the accounts.

It was not intended to give here more than a very general outline of the scheme of accounts necessary for the conduct of an electric light company, to emphasize their importance in maintaining close touch with all important transactions of the business, to show how they provide ready comparisons, and to point out their usefulness in detecting increases or decreases in expense or income, and, in short, to facilitate the economical conduct of the enterprise.

Bond Interest, Stock Dividends, Etc. Before the *net* profit or surplus belonging to the stockholder is reached, however, several very important general factors must receive consideration. Thus far we have dealt with specific items of distribution and income of a tangible nature, and which can each be allocated to a definite division or subdivision of the accounting system. Non-operating items of income and expense being of local significance only, can be disregarded here, but interest on bonds and depreciation reserves are common to all enterprises and must, therefore, be taken into account. Bonds are issued for the general purposes of the business, and can very rarely be identified with specific items of investment.

The accounting system discloses the operating cost of current delivered at the switchboard of the generating plant, but to obtain the total cost there must be added interest on the amount invested in real estate, buildings, plant and equipment, and a proper allowance for depreciation. As a matter of practice bond interest is

usually deducted in one item from the net operating profit. Similarly also the item of depreciation.

Rate Schedules

There is no subject with which the administration of an electricity supply company is concerned, about which there is such a wide diversity of opinion as the system of charging for the current sold or the schedule of rates. It was recognized in the early days of the industry, almost at the same time that the incandescent lamp itself became a commercial possibility, that in order to secure success to the electric companies they must be provided with proper means to measure the current delivered to the consumer, and that it must be paid for in accordance with the quantity consumed as recorded by the meter. The basis of charge, rate schedule or tariff to which the meter records shall be applied to produce the consumer's bill, present in their preparation the most difficult problems with which the management has to contend, and the endeavor to arrive at a satisfactory solution will call forth all the resourcefulness and skill which it can command.

Philosophy of Rates. To attack this problem requires an accurate knowledge of the business of the company, its various classes of consumers, the extent and the way each class makes use of the current, the necessity of meeting the competition of other illuminants and the competition of the private plant; also an appreciation of the importance of the presentation of the rate to the public in a form that will be at once simple, logical, and easily understood—that provides a reasonable relation between the price charged and the cost of the service rendered—and that accomplishes the important end of encouraging the profitable consumer, attracting all classes of consumers, and, finally, providing an adequate revenue to the company.

These are, indeed, diversified, and, to a certain extent, incompatible requirements, and to find a reasonably satisfactory solution calls for compromise between the desirable and the attainable. Learned discourses may be written on the relation of cost to selling price, the relation between the rate and the value of the service rendered, on where classification ends and discrimination begins, on increment costs and what the traffic will bear, and on sliding scales, differential tariffs, etc., but they will be of comparatively

little assistance when it comes to formulating a rate. Each station manager, when this subject is presented to him, after studying the analogies afforded by other industries, and after making a careful study of the rates of other companies similarly situated, finds not one entirely satisfactory or adapted to his particular local conditions, and he forthwith proceeds to devise a new method of charging or of changing the discounts or values on some schedule already in operation, making more or less of a misfit. As early as 1892, in the classic on "The Cost of Electricity Supply," by Dr. J. Hopkinson (presidential address, read before the Junior Engineering Society, Manchester, England), this subject of rates received analytical treatment by a master hand. This paper should be the station manager's primer on this subject, as it contains (even though now quite out of date) a clear statement of the underlying principles on which the establishment of a logical system of charging should be based, although his practical application of the principles would not satisfy the requirements of to-day.

In this paper, under his preliminary considerations, Dr. Hopkinson says:

"You are all familiar with the fact that the expense of an undertaking may be broadly divided into two classes. On the one hand there are expenses which are quite independent of the extent to which the undertaking is used; and on the other, expenses which are absent unless the undertaking is used, and which increases in proportion to the use. For example, the charges for interest on the construction of a bridge are the same whether that bridge is used much or little or at all, and the cost of maintaining the bridge is also practically independent of its use. The same is true in a large measure of a harbor or a dock. Such undertakings lie at one extreme of the scale. It is less easy to find good examples at the present day of the other extremes, as nearly all undertakings with which engineers have to deal require the employment of some capital, and there will be a fixed charge for the use of that capital and for maintaining against the assaults of time the things in which the capital is embodied. But we can readily see, for example, in the case of a cotton mill, that, if on the one hand there are expenses of interest and dilapidation which are independent of the amount of yarn actually manufactured in a given factory, there are other expenses for material and labor, and even for actual wear of machinery, which will be very nearly proportional to the output. Undertakings vary enormously in the proportion of these two classes of expenses; on some the expense is quite independent of the extent of the use, in others it is for the greater part proportional to the use. But undertakings differ from each other in another

respect. In some cases a service which the undertaking is designed to render can be performed at a time selected by the undertaker; in others at a time selected by him to whom the service is rendered. In the case of most manufacturers it matters not if the thing made is made to-day or to-morrow, in the morning or in the evening, for it will not be used for a month hence, perhaps; the thing can in fact be extensively stored and kept till it is wanted. Other services must be rendered at the moment a person served desires. For example, the Metropolitan District Railway must be prepared to bring in its thousands of passengers to the city at the beginning of the day and take them back in the evening, and for the rest of the day it must be content to be comparatively idle. In this case the services cannot be stored. The line must be of a carrying capacity equal to the greatest demand, and if this be great for a very short time the total return for the day must be small in comparison with the expense of rendering the service. In such a case it would not be inappropriate to charge more for carrying a person in the busy time than in the slack time, for it really costs more to carry him. Let us see how these considerations apply to the supply of electricity for lighting. Electrical engineers now realize that they have to provide the same plant and no more to give a steady supply day and night as to give a supply for one hour out of the twenty-four. They also now realize that if they are to be ready to give a supply at any moment they must burn much coal and pay much wages for however short a time supply is actually taken. Indeed the term load factor proposed by Mr. Crompton is as constantly in the mouths of those who are interested in the supply of electricity as volt, ampere or horse-power. The importance of the time during which a supply of electricity is used was so strongly impressed on my mind years ago that in 1883 I had introduced into the provisional orders, with which I had to do, a special method of charge intended to secure some approach to proportionality of charge to cost of supply. Unfortunately the orders of that day all came to naught. A supply of electricity must be delivered at the very moment when the consumer wishes to use it, and as long and no longer than he pleases to use it; it cannot be very readily or cheaply stored, and much of the cost of production is fixed charge for plant and conductors. Furthermore, the provisional orders require that the supply shall be available at all hours; hence coal must be consumed and workmen must attend, though but few consumers are drawing supply. The service of supplying electricity has, from an economic point of view, a great deal of similarity to the service of providing a breakwater for an harbor. A great deal of the expense is independent of the number of hours in the day during which the supply is used. To put it in another way, the cost of supplying electricity for 1000 lamps for 10 hours is very much less than ten times the cost of supplying the same 1000 lamps for one hour, particularly if it is incumbent on the undertaker to be ready with a supply at any moment that it is required. The actual importance of considerations of this kind can only be realized by examining figures."

We will not follow Dr. Hopkinson in the figures he presents, but will add his own conclusions from their analysis:

"The ideal method of charge, then, is a fixed charge per quarter proportioned to the greatest rate of supply the consumer will ever take, and a charge by meter for the actual consumption. Such a method I urged in 1883 and obtained the introduction into certain provisional orders of a clause sanctioning 'the charge which is calculated partly by the quantity of energy contained in the supply and partly by a yearly or other rental depending upon the maximum strength of the current required to be supplied.'"

It should be pointed out that the system of charging proposed in this paper was suggested by Prof. G. Colombo, and used by the Italian-Edison Company, operating the Edison station at Milan, Italy, as early as 1885-1886.

Let us consider for a moment the unit of charge. At first that most indefinite unit, the lamp-hour, was in current use; then the ampere-hour, still in use to a certain extent; and, finally, the kilowatt-hour—to which it has been proposed to assign the name of the illustrious Kelvin—and which conveys an exact measure of the energy supplied to the consumer, whether that energy be applied for light, heat or power purposes.

Flat Rates. The flat-rate system of charging a fixed price per unit (a fixed rate per kilowatt-hour), which prevailed to a certain extent in the early years of the industry, is not based on any logical principle, does not result in an equitable charge to the consumer, and does not provide a fair return to the company.

This form of rate does not encourage the profitable consumer, makes it impossible to express in the rate the relation between the price charged and the cost of supply, and makes it impracticable to establish any classification; it is absolutely inflexible, and, in short, utterly fails to recognize the essential conditions of the business. Such a rate is quite out of consideration as utterly unadapted to the business of electricity supply, however satisfactorily it may meet the conditions of gas supply.

In some instances an effort has been made to partially overcome the inflexibility of the flat-rate system by establishing varying flat rates based on a classification of the service into power, heating, storage-battery service, etc.

Rate Differentials. The formulation of a special price for charging storage batteries has a logical basis on the score of

diminished cost to the supply company, provided the hours of charge are limited to hours when part of the station machinery would otherwise be idle; the current can then be sold at a decreased price, no additional capital investment being required for station equipment, if the hours of the station's maximum load are excluded. Moreover, the current required for charging is quite constant, and it extends over a considerable period, normally 5 to 10 hours, and it can, therefore, be generated at a low cost.

Current for industrial motors is usually supplied at a lower price per unit than current for incandescent lamps, even excluding the cost of lamp renewals. While the load factor of the average motor is much better than in the average incandescent installation—the average use per unit of connected capacity being considerably over double that of an incandescent installation, while the maximum yearly demand per connected unit is less than one-third of an equivalent incandescent installation—it would seem that this special characteristic of the motor load entitling motors to lower rates per unit of current might better be taken care of by the application of one of the systems to be referred to later on rather than by fixing a lower fixed rate for this class of service. Moreover, some classes of motors, for instance, elevator motors, do not have these favorable characteristics, and owing to the low return they give per unit of capacity or maximum demand, and the intermittent nature of the service requiring special precaution to avoid interference with the lighting service, they should not be entitled to such special consideration. This difficulty is often met by fixing a minimum charge per month per unit of capacity or of maximum demand.

This system of classified rates does not fully accomplish the purpose of a flexible differential rate system, and preserves to a large extent all the disadvantages of the single flat-rate system.

We now come to a consideration of some of the several differential rate systems. In applying practically the Hopkinson, or as it is called, the Manchester system, a fixed price, sometimes varying in amount, is charged for each kilowatt of "*installed*" capacity (installation equivalent) plus a price per kilowatt-hour, the unit price sometimes varying in amount according to a sliding scale.

The Manchester or Hopkinson system has, in general, however, a serious objection—it discourages the installation of lamps excepting where they are burned for long hours, or where they are con-

sidered a necessity. The consumer loses the great convenience of lamps installed in closets or other situations of rare or intermittent use, and he has no inducement, but, on the contrary, is deterred *from* using the electric light throughout his building. It also tends to make the cost of purely residential lighting prohibitive, as the high price which it is necessary to make as a fixed charge per month or per year, exclusive of the actual consumption, puts the cost of electric light out of the reach of the average householder.

In this sliding scale or variable price per unit schedule, we have an effective method of giving a premium in the shape of low rates to the long-hour consumer. It is not altogether satisfactory, however, in that it fails to give proper recognition to the wholesale, or quantity, consumer.

The gross bills, or the total units supplied, are divided by the installation equivalent to determine the average hours use per month per installation equivalent; the bill at the end of the month is made up according to a sliding scale of rates based on the average use of the installation. For instance, 15 cents per kilowatt-hour would be charged for a consumer using his installation an average of 1 hour per day for each lamp installed, 13 cents per unit in case the average use per lamp installed reaches 2 hours per day, 12 cents for 3 hours' use, etc., etc.

Horse-Hire Analogy. This system does not, as above pointed out, reach the wholesale customer at all, but considers only the advantages of long hours' use of the installation. As a practical illustration of the relation of long-hour use, enabling a rate to be made even below the average cost of current the following analogy may be used: If a stable-keeper had four saddle-horses, which cost him for investment and keep $1.00 a day each, he might let one horse at $1.00 an hour, and if for only 1 hour in the day he would get no profit out of him. But if he let a second horse at 75 cents an hour for 2 hours, he would make 50 cents profit. A third horse hired for 4 hours at 40 cents an hour would make 60 cents profit. And if he let the fourth horse at 25 cents an hour for 8 hours, he would make $1.00 profit from him. The four horses would have cost him $4.00 per day, or 26⅔ cents an hour for each of the 15 hours of use. He would have received from them $6.10, or 40⅔ cents per hour of use, and he would have made the most money out of the customer to whom he charged 25 cents an hour, or less than the average cost.

Rate Discounts. Recognizing the deficiencies of all the foregoing systems, a schedule has been devised, and is being extensively used in Europe and America, which takes account at the same time of the claims to consideration of both the wholesale, or quantity consumer, and of the retail, but long-hour consumer, by providing a discount based on the amount of gross bills or units supplied, and an additional discount based on the average use of the installation, the importance given to each class being governed in each case by the relative values of the discounts given under each head. This system enables the company to show its appreciation of the importance to its business of the consumer using large quantities of current, and in addition recognizes his further claim to consideration if he uses his installation on the average for a considerable number of hours each day by giving him an additional discount. It also enables the company to recognize in some degree the desirability of the small, but long-hour, consumer by giving him discounts on his bills based on long average use, even though his bills may not run high. Some companies choose to make these two discounts cumulative, adding the quantity discount to the long-burning discount to arrive at the net bill; others take off first one discount from the bill, and from the resultant net take off the second discount.

The objection to this system of charging for current, and to many of the schedules already referred to, is that they do not preserve a uniform proportional relation between gross and net bills all along the schedule; in other words, the curve of discounts is not smooth, but broken into steps. For instance, in a schedule under which a discount of 5 per cent is allowed on a $100 bill, a consumer using current representing a gross bill of $100 would get his current for $95, whereas a consumer using current representing a $98 gross bill would pay the full amount ($98), or actually more than the first case, although a smaller amount of current had really been supplied. This shortcoming may, however, be taken care of in the figuring of the bills by making the necessary adjustment on the bill so that no consumer will be charged a larger price for a smaller amount of current actually supplied.

It may be well to refer here to a factor in the determination of the discount in the systems mentioned thus far, which has been made the subject of much discussion of late, i. e., the "equivalent" unit of installation (installation equivalent) as a basis on which to figure discounts.

It is very difficult, particularly in large installations where changes are made almost daily, to keep track of the exact installation "equivalent" and to check it at the time of each meter reading would be impossible. The alternative, the substitution of the unit of maximum demand as a basis for determining the average use, is certainly more logical and gives to the more profitable consumer a further advantage to which he is justly entitled. It requires, however, the use of special apparatus in addition to the ordinary supply meter, and this introduces a serious and very undesirable complication.

Wright Demand System. We now come to the Wright or Brighton demand system.

If the accounts of an electricity supply company are analyzed, it appears at a glance that the amounts entering into them can be classified under two general heads: Fixed Charges—dividends on capital stock, interest on bonds, depreciation, a part of the expenses of management, taxes, insurance, etc.; and Operating Charges—coal, labor, repairs, supplies, etc.

From a first analysis it will appear that the items coming under the first heading are largely independent of the output, and would, generalizing broadly, go on even if the company ceased operating. The items under the second head will appear to bear a certain relation to the output, increasing with, but perhaps not strictly proportional to, such increase.

On further and more detailed study of the monthly accounts and making comparisons extending over several years, it will appear that certain items under the second heading are also practically fixed, and while appearing under the head of *operating* expenses, they are quite independent of the output, and represent a class of expense intermediate between the fixed charges and an operating expense. These intermediary expenses, usually generalized under the term "standby" charges, cover a part of the coal, a part of the labor, some supplies, etc. They represent an intermediary step between the expenses incident to the organization of a company and the expenditure of capital for prospective future operating and the actual regular operating or purely "Running Costs."

They are a class of expense which a company would be under in merely *getting ready* the plant for instant service; part of the station force on hand, steam up, steam pipes hot, steam traps, taking care of condensation, etc., etc.

It will appear evident that these items will amount in the aggregate to a considerable sum, and many of them would go on continually night and day, winter and summer, even if the plant never actually put out current, and they are quite independent of the amount of such output if operating actually begins. They represent the expenses a company is under in getting ready to serve a customer *instantly* on his *immediate* demand. These so-called "*standby*" charges will also be found to bear a certain relation to the amount of the maximum demand (kilowatt), and not necessarily to its duration (kilowatt-hours). They are, therefore, in the nature of a fixed charge, and may be logically considered as such in making an investigation as to the cost of electricity supply and the price at which electricity can be sold to the consumer.

To make a charge to a customer of a fixed price per lamp, whether he uses it or not, even if that fixed charge be only a part (though necessarily an important one) in the total price of the current, is to him obnoxious and illogical, and, moreover, has the tendency already pointed out to limit him in his installation to only such lamps as he uses continually.

Mr. Arthur Wright, of the Brighton (England) Company, many years ago, having these facts in view, devised a system according to which each consumer shall pay to the company his equitable quota of the strictly fixed charges and also of the standby charges. He included these charges in the charge per hour made for the first hour's use of a number of lamps equivalent to practically the maximum number of lamps he used contemporaneously, and for the current used in excess of the first hour's average use of his maximum demand he charged the customer a different rate, which is proportional to the additional expense which the company is under in supplying him with the additional current.

For instance, in his Brighton station in 1896, the charge for the first hour's use of the maximum demand was 7 pence (14 cents). When the equivalent consumption of 1 hour's use of the maximum demand had been taken, the further supply taken was charged for at the rate of only 3 pence (6 cents) per unit.

In order to apply this system to any given case, it is necessary to make a careful analysis of the company's accounts to determine the proper ratio between these two rates. Mr. Wright started out with the proposition that once a customer asks for current supply he should pay his quota of fixed and standby charges (covered by the

rate charged for the first hour's use of maximum demand) in the ratio which his maximum demand bears to the maximum demand of all the consumers—on the basis, that he actually found to be the case in Brighton, that the maximum demand on the station is only 66 per cent of the sum total of the consumers' maximum demands. This assumption is not strictly correct or altogether logical, as the fixed charges and the standby charges ought rather to be apportioned to each consumer in proportion to his maximum demand *at the day* and *very hour* the maximum load of the year occurred at the station. As it is impossible to determine this in practice, Mr. Wright, therefore, made the above generalization and assumption as a near approach to the theoretical requirements of the case.

This system requires the installation of a special instrument to determine the maximum demand, for which the "Demand Indicator" was devised, which indicates at the end of a given period the maximum current (amperes or kilowatts) supplied to the installation.

By inspection of the demand indicator the consumer can see directly how many units he must take at the high rate before he can enjoy the low rate for any additional supply.

This form of rate is based upon the fundamental principle of making of every consumer a profitable customer, and automatically placing upon each a proportionate burden of the fixed and standby charges. The Brighton rate has lost considerable of its popularity in late years, even in England, and in the City of Brighton itself, and it is now viewed as failing to recognize certain important commercial principles, and in order to apply it practically, it is necessary to modify it considerably, making it rather complex. It is based, however, on a theoretically correct principle of charging and recognizing certain fundamental features in the relations between the rate and cost of supply.

Kapp System. Another rate which should be considered here briefly is the two-rate or Kapp system of rates, based on the *time* of the maximum demand of the consumer as compared with the time of the station's maximum load.

There is an essential difference between this two-rate system of rates and the Wright demand system; whereas, in the former the rate is based on the relation between the customers' maximum demand and the maximum demand of the station as a whole, in the

latter case the rate is based on the customers' maximum demand and a demand which is not the station maximum, but the assumed sum total of the maxima of all the consumers. If, as has been generally admitted, it is equitable to grant discounts to the most profitable consumers, it follows that the consumer who, for the same total current supplied to him, contributes least to the station maximum load should benefit most largely by the discount. It is quite reasonable that all consumers should pay some proportion of the standing charges, but it is not altogether reasonable, at least theoretically, to charge an early morning consumer, whose demand ceases before the hour of the station maximum, the same rate as a consumer whose demand requires an additional capital investment in station equipment.

In applying this system at first, a switch was installed, the duty of which was to automatically control the registration of the meter in such a way that the current consumed during certain limited hours shall be charged for at the full rate, and the current consumed during the remaining hours of the day shall be charged for at a reduced rate.

Where the system is in use at the present time a two-rate meter is installed which automatically controls the registration, the time periods being adjustable. In the practice of some electric lighting companies, usually where the current is generated by water-power, a special rate is made to mills and factories who agree to shut down their industry during the duration of the "peak," usually an hour to an hour and a half.

Nearly all of the differential or classification rate systems at present in use are either a combination or a modification of one or more of the principles above outlined.

A very common system is in use in this country which seeks to accomplish the same results as the Brighton system, without using the individual customers and avoiding the installation of a separate "demand meter" by using the customer's total installation equivalent as a basis for determining the average use of the installation, basing the rate on the general average ratio of total installation equivalent to total demand of all the consumers in the class, and providing a sliding scale of discounts or prices depending upon the hours average use of the total installation. Another modification in use to some extent in this country subdivides the charges as applied under the Manchester system into four separate factors.

Wholesale or Bulk Supply. The above systems are all directly applicable to retail lighting, and also power schedules by proper pricing, and it is usual, in applying them to retail power schedules, to make a lower price for power recognizing the long-hour use of this class of service where the rate itself does not give this factor full consideration. All of the above rates, in principle at least, omit to recognize that when large quantities of current are sold it is proper and equitable to make a better rate than for a small retail user, on account both of the lesser cost of supply under these conditions, from the broad commercial viewpoint, and from the standpoint that it is absolutely necessary to secure this class of business—which is oftentimes competitive—and to obtain it a lower rate must be made which may provide a smaller margin of profit than the other classes of business. It is recognized that such wholesale or bulk supply, while the proportionate contribution which the rate provides, for application to the fixed and standby charges may not be so large as in the case of the retail consumers, it still provides a sufficient margin to apply to the reduction of prices to the retail consumer, who may thereby obtain service at a lower rate than if the company were not in a position to obtain this business, for which it can only obtain a price which would compare with the market price of home production or of other competitive means of rendering the service.

In "American Railroad Rates," by W. C. Noyes, this question is referred to in the following terms:

"Competitive traffic stands upon the same basis as long distance traffic; at points upon the railroad where there are carriers—water or rail—the road must meet competitive rates to obtain competitive business. In order to meet these rates it may be necessary to reduce its charges to an extent which, if applied to the whole business, would throw the road into bankruptcy. There are only two alternatives. It may *not* compete, in this case non-competitive traffic must bear the entire expenses of the railroad. It *may* compete, and while the rates may be low there will still be a small surplus which will help, so far as it goes, the non-competitive traffic to pay expenses."

In rendering service to wholesale customers the current is used for all the purposes to which it can be applied—lighting, power and heating—all of which is usually metered in bulk and a single bill rendered for the combined service.

The wholesale rates and contracts often contemplate other matters than mere current supply, such as providing room on the

premises for converting or distributing apparatus, switching gear, etc., and unlike retail rates the contracts do not generally provide for the free renewal of incandescent lamps or the care and maintenance of arc lamps. These wholesale rates usually take the form of a special discount for quantity used applied to the standard or retail rate on one or the other systems above outlined, or are based entirely on the quantity of current used or total amount of the bills per month or per year. In some cases they are based on minimum guarantees of consumption, and in others on reaching a minimum of monthly or yearly bills.

It is usual to formulate special rates in contracts with the city authorities and other public bodies, and these need not be referred to here.

"Breakdown" Service. Public service corporations are often called upon to supply a special character of service used as a reserve, auxiliary or insurance against the breakdown or failure of an isolated plant. It is the policy of some stations not to supply this unusual kind of service, but where contracted for it is usually done on specific agreements for each case or on the basis of a minimum guarantee.

Railroad Service. Another special kind of service, usually supplied by the larger companies, is for high-tension current furnished usually in considerable quantities and delivered as high tension, either at the switchboard of the company's generating station, at a substation, or at the consumer's premises.

It is usually a *bulk supply* for railroad service—furnished to local authorities to be distributed by them—or for large industrial operations like compressor plants, pumping stations, etc.

This service is usually rendered on the basis of a fixed charge per kilowatt of maximum demand plus an operating charge per kilowatt-hour delivered.

As before stated, the rates for electricity supply must be flexible and adaptable to all these different classes of service. In a recent paper on "Price of Electricity Supply," by E. W. Cowan, read before the British Association, he says:

> "A business is not and cannot be made wholly a machine, it is more akin to an organism and as such must develop powers of adaptation to varying conditions which are beyond the range of the functions of mere mechanisms."

and again

"The attempt to reduce business to a process of mechanically grinding out equal percentages of profit upon all operations renders the obtaining of the maximum aggregate profit to producers and consumers impossible."

"With a scientifically adjusted scale of charges, having due regard to the market price of each class of commodity supplied whether light, power, heat, etc., it is possible in many cases, not only to confer benefits upon the power and heat users, but to supply the light user at a lower price than would be possible if the principle of a uniform rate of profit from each class of consumer were adopted."

Metering

The proper metering of the energy delivered by an electric lighting company to the consumer is one of the important functions of the company, and lies at the very foundation of its success. It is obvious that the supply meters should register correctly for the protection of both the consumer and the lighting company. From the standpoint of the consumer the meter furnishes the record on which his individual bill is based, and it is the duty, therefore, of the company to provide proper types of meters on the consumer's premises and maintain them in a condition to record his current consumption accurately, in order that proper bills for the energy delivered may be furnished to the consumer.

From the standpoint of the lighting company the meter is the apparatus which registers and determines the amount of its income, it is, therefore, also, in the interest of the company to maintain its meters in proper condition to insure the receipt of its rightful revenue. The loss of revenue occasioned by slow meters can properly be considered an increased cost of distribution, and an increased cost of distribution would need to be met with a higher rate. Under such conditions the consumer whose meter is accurate would be paying in part for the loss occasioned by the slow meters in other consumers' premises. The proper equalization, therefore, of rates and charges makes it necessary to insure the continued maintenance of the accuracy of the supply meters.

Limits of Accuracy. The statement that meters are to be maintained in accurate condition naturally raises the question of what constitute the limits of accuracy within which a supply meter can be considered as commercially accurate while in operation on the consumer's premises. It appears to be reasonable to allow a lati-

tude of 5 per cent on either side of absolute accuracy, when the meter is tested *in situ* on the consumer's premises, and a commercially accurate meter, under these conditions, may, therefore, be defined as one registering less than 5 per cent fast, and less than 5 per cent slow when compared with absolute accuracy. These limits are quite fair for direct-current meters which are all of the commutator type; they could possibly be restricted somewhat for induction meters.

Conditions of Test. A meter used in the consumer's premises should preferably be calibrated on the premises under the actual conditions of use. It is quite impossible for the purpose of a test *in situ* to surround the meter with laboratory conditions or to bring to it the precision standard instruments used for obtaining the extreme refinements of accuracy possible in a laboratory. For the tests on the customer's premises instruments must be used which combine a high degree of accuracy with portability. The majority of meter tests necessitate readings and observations obtained by two men on from two to four calibrating instruments. Possible errors may arise in connection with each of the measuring instruments and the two observers. These possible errors while individually small may be cumulative, and may easily introduce a final error in excess of 2 per cent. Tests on consumers' premises should, therefore be put on a different basis from tests in the laboratory, and the above facts should be taken into consideration when studying the various laws and regulations which have been enacted in several States.

Municipal Requirements. Some of the laws defining legal metering accuracy enacted thus far are as follows:

PUBLIC SERVICE COMMISSIONS LAW FOR THE STATE OF NEW YORK

Paragraph 5, page 68

If any consumer to whom a meter has been furnished shall request the commission in writing to inspect such meter, the commission shall have the same inspected and tested; if the same on being so tested shall be found to be more than four per centum, if an electric meter, or more than two per centum if a gas meter, defective or incorrect to the prejudice of the consumer, the expense of such inspection and test shall be borne by the corporation or municipality, if the same on being so tested shall be found to be correct within the limits of error prescribed by the provisions of this subdivision, the expense of such inspection and test shall be borne by the consumer.

Railroad Commission of Wisconsin
Ruling of the Commission, July 24, 1908
Ruling No. 15

No electric meters shall be placed in service or allowed to remain in service, whose error of registration is in excess of 4 per cent at light load, half load or full load.

Massachusetts Commission
Section 36 Revised Laws
Chapter 121

A meter shall be deemed correct for the purposes of this section if it appears from such examination or test that it does not vary more than 5 per cent from the standard approved by the Board.

Canadian Laws
6-7 Edw. VII
Section 15

No meter shall be correct which is found by the inspector to register quantities under or over the legal standard of electricity, more than 3 per cent in favor of the contractor or purchaser.

Aside from the more or less definite limits of accuracy established by these local enactments, the laws are usually silent in reference to the method and form of test and place where it is to be made. In applying the New York State law the Public Service Commission of the First District has promulgated regulations as to the method to be followed in conducting the tests. They provide that three readings be taken, one at light load, or about 10 per cent of meter capacity; one at full load, or approximately 100 per cent of meter capacity, and a third at what is called "normal load." This normal load is the load at which it is assumed the consumer generally uses the current, or at least most of it, and it is taken to be represented by a certain percentage of the meter capacity as prescribed in an empirical schedule formulated by the commission. This schedule for determining the normal load is as follows:

Classification of Installation to be Used in Testing Meters at Normal Load

A. Residence and apartment lighting	25%
B. Elevator service	40
C. Factories (individual drive), churches and offices	45
D. Factories (shaft drive), theaters, clubs, entrances, hallways and general store lighting	60
E. Saloons, restaurants, pumps, air compressors, ice machines and moving-picture theaters	70
F. Sign and window lighting and blowers	100

When a meter is found to be connected to an installation consisting of two or more of the above classes of loads, the normal load used must be obtained by taking the average of the percentages for the classes so connected.

These three readings as above defined are then combined into what is known as the final average accuracy of the meter, by the following arbitrary method: The light-load and the full-load accuracies are added to three times the accuracy at normal load and the result divided by five (5), the quotient is the full-load accuracy. This is equivalent to assigning in the computation a determining value to the normal load of three times the light load or full load.

The testing and *sealing* of meters while in the meter laboratory, before installation in the consumer's premises is also specified in some of the legal regulations, notably in Canada. This method while entirely practicable when applied to gas meters is quite impracticable when applied to electric meters, particularly of the commutator type. It is absolutely essential to the proper calibration and adjustment of a meter that access to the moving element be obtained during the test, and any subsequent adjustment that may be necessary. Experience has shown that it is desirable that meters be calibrated *in situ* under the service conditions obtaining on the consumer's premises. The local electrical and general physical conditions immediately surrounding the meter in the premises where it has to operate are the conditions under which the meter should be tested.

Approval of Types. The approval and testing of meters abroad, notably in Great Britain and Germany, takes the form of approval by the regulating authority of the *type* of meter rather than of each individual meter. In this country the State of New York Public Service Commission for the First District has also adopted this procedure, and it was necessary for the operating companies to obtain from the commission approval of the various types of meters already in actual use by the companies operating in the district. Several meters of each type were subjected to a rigorous series of tests specified by the commission, and types of meters that successfully met the requirements were formally approved for use, and those which did not were rejected by the commission as not being proper meters for use in the consumer's premises. The various tests to which the several types of meters were subjected, covered, with the mechanical construction

of the meters, the range of the adjustments and the performance under the varying conditions to which the meter might be subjected when in service.

The tests covered the performance under the following conditions:

Variation of load and of voltage,

Variation of temperature,

Effect of temporary overload,

Effect of nearby conductors carrying current;

and in addition for alternating-current meters,

Effect under change of power factor,

Effect under change of frequency.

Fast and Slow Meters. It is evident that the framers of State and local regulations have not adequately considered the question of meter operation in all of its aspects. While accuracy limits for fast meters are established in some cases, nothing is said in the law about slow meters, whereas meters in this class greatly outnumber those that are found fast. It is found that in the case of complaint tests roughly 85 per cent of the meters tested have been found within the legal limits of accuracy, of +4 and −4 per cent from absolute accuracy, and about 4 per cent have been found fast or outside these limits, and the balance, 11 per cent, have been found to be slow. In the case of the regular periodic tests it is found that approximately 80 per cent of the meters have been found correct on test, only 2 to 3 per cent have been found to be fast and the balance, 17 to 18 per cent, represent meters which on the average have been found to be slow.

Nothing has been said here of what should be done with records of the slow meters—those showing an accuracy below the inferior limit of approved accuracy. It would be eminently proper and just to ask the consumer to pay the company for the current he has used, but which was not properly registered by the meter and, in fact, in some cases such a course is pursued, but, as a general rule, and as a matter of business policy, the companies have not assumed to collect for the shortage due to slow meters. If the meter, on account of some defect, should show no record at all, the consumption is agreed upon with the consumer on a basis that is in all cases entirely satisfactory to him.

The refunding to the consumer of a certain percentage of the revenue derived from a meter which has been found to register

in excess of the limits of proper accuracy is not governed by any exact rules. The period for which such refund should be made should take into consideration the elapsed time since the last previous test at which the meter was found or left registering accurately but this affords no clue as to the time at which the over-registration began or whether the deviation from accuracy was a gradual or a sudden process. The usual bases for adjustment are as follows:

A certain number of months regardless of the length of time to the last test.

One-half of the period; adjustment with the consumer.

The agreement with the consumer as to what is the proper period over which the adjustment should be operative or the amount of the refund is a proper matter of adjustment between the company and the consumer, unless based on some agreement with the proper supervisory authority.

In some companies the period over which the adjustments are made is taken as a full allowance of the excess over 100 per cent accuracy for one-quarter of the period back to the last previous test, a certain number of months regardless of the elapsed time, or one-half the period, or one-half the rate of excess for the full period. The practice of the companies operating under the jurisdiction of the Public Service Commission of the First District, New York State, is to allow the full rate in excess of 100 per cent accuracy for one-half the period back to the last previous test.

Periodic Tests. Meters to be maintained in a condition of proper accuracy should be tested at certain periodic intervals; the length of the interval between tests should be regulated by local conditions. As a general principle meters should be tested often enough to maintain them in operation at the highest accuracy, but the cost of the test should not be allowed to exceed the loss of revenue where the tendency is, invariably, for the meters to run slow, but they should not be tested so often as to be a source of irritation and annoyance to the consumer.

The results obtained, year by year, should be carefully scrutinized by the meter department, and should be used as the basis for the determination of the proper period for the periodic test of its meters.

Complaint Tests. In addition to the periodic tests the meter departments of the best equipped companies are called upon to

make tests called for by the consumer, witness tests conducted by the Public Service Commission or by the city authorities, inquiry tests originating with the company for the purpose of investigating the cause of abnormal and unexplained fluctuations in the registration of individual meters, and various other special tests.

Maximum Demand Meters. Maximum demand meters or indicators are instruments which give a record graphic or visual of the maximum load which has prevailed in the consumer's circuit during any given time. These instruments are not designed to indicate instantaneous maximum points, but rather to record maximum loads existing for some more or less definite period. These maximum demand instruments may be of various types; one leaving a record by means of a maximum reading pointer and another consisting of a printing attachment connected with the regular watt-hour meter register. This latter form of instrument prints at certain predetermined periods the demand for the preceding interval. A visual type reads off the maximum demand on a graduated mercury column.

Location of Meters. The proper location of meters and services in the consumer's premises is an important factor governing their maintenance. Care should be taken at the time of installation to insure that the best available location is selected. Unfavorable conditions to be guarded against are, vibration, possible corrosion due to dampness or acid fumes, dust, mechanical damage, proximity to conductors carrying heavy currents, etc.

As stated in a recent report of the National Electric Light Association:

> "The electric meter operates under more varied and exacting conditions than almost any other piece of apparatus. It is frequently subjected to vibration, moisture and extremes of temperature; it must register accurately on varying voltages, frequencies and various wave forms; it must operate for many months without any supervision or attention whatever; and in spite of all these conditions it is expected to register with accuracy from a few per cent of its rated capacity to fifty per cent overload."

It would appear that the attitude of suspicion with which the public is apt to regard the electricity supply meter is entirely unjust and altogether unwarranted, as appears from the wide experience of the operating companies and by the results of the numerous official tests of the public service commissions and other supervisory authorities.

Advertising and Canvassing

"Show Rooms." One of the most important and effective agencies for promoting the business of an electric light company is the show room, a tastefully decorated, handsomely furnished store in the center of the town, and on its main thoroughfare where all the latest electrical devices are on exhibition. The show room should be a model of good taste, pleasing to the eye, yet modest and subdued in its prevailing tone, so as not to detract from the goods on display.

Here should be found all the very latest devices for the home, and the many novelties and conveniences which contribute so much to popularizing central station electric service.

There should also be on exhibition some of the practical applications of electricity to industrial uses with live demonstration apparatus, and, as far as practicable, some of the simpler types of electrically operated machinery.

A well-equipped show room, or a number of them, if the territory requires it, should be effectively lighted, thereby establishing a high standard for all of the surrounding shops and setting an example of the best methods of illumination which will make a strong appeal to the enterprising merchant who is ever alert to display his goods to the best possible advantage.

Agency Service. The progressive company will always have an efficient staff of agents and canvassers, men of good address, courteous to the public, and well informed on the different subjects they are to present to the prospective customer. The best results will be obtained by having different agents handle the various branches of the business; solicitors for power service confining themselves to that particular field; canvassers for wholesale business, for isolated plants, for heating and cooking, for automobiles and battery work; illuminating engineers and other specialists.

These men should be experts in their several lines, well posted on all the latest developments, resourceful in making useful and helpful suggestions to customers, and familiar with the general public policy of the company. They should constantly have in mind that they represent the company to the public, and should not bear their responsibility lightly.

In a smaller company the individual canvasser will find it necessary, of course, to cover a much broader field, and he must.

therefore, be an all round man, generally, posted on all branches of agency work.

Illuminating Experts. In no class of electrical application is the consumer so much in need of expert advice as in the matter of illumination, and a competent staff who can give sound advice to customers as to how to light their stores and shop windows most effectively and most economically should be at the service of the public.

A well-lighted shop window is a good advertisement for the company as well as the merchant, and it is necessary to eliminate the black and shady spots in the brightly lighted thoroughfares, and a resourceful illuminating engineer with an energetic staff will soon weed them out.

Power Experts. The average customer is not familiar with electric power applications and needs expert assistance to advise him as to the best method of applying his motors, whether individual drive or group drive, and on such matters as the most economical speeds of operating tools, the power required to drive the various classes of machinery, etc.

In all of these directions the company can be of the greatest assistance to its customers and aid them in saving money in cost of equipment and operation.

The power expert should be capable of conducting an engine and boiler test, if necessary, take engine indicator cards with and without load to determine the power consumed by shafting, and be able to suggest means to eliminate losses from improper alignment of shafting and pulleys. He should be able to advise as to the best practice in methods of speed control of motors and be familiar with the characteristics of the different types of motors.

The company should, in its newspaper advertising and by circulars, invite the customer to avail himself of the services of the company's experts, and he should be given to understand that they are available at all times for the asking.

Newspaper Advertising. Much might be said on the subject of newspaper advertising, but we must confine ourselves to some general consideration.

Newspaper advertising is a form of publicity most necessary to the progressive company, and it is one of the most effective methods of keeping itself prominently before the public.

A corporation (or firm) is known by its advertising, and it follows, therefore, that its newspaper advertising and, in fact, all forms of publicity should be dignified, striking, and such as to carry home to the reader at least one definite idea. The advertising matter should be very carefully prepared, remembering that the company is advertising to advertisers; and particularly the mail matter must be of the highest possible quality. Where the card is illustrated the sketch should be well done, in concept and execution.

Advertising usually can be placed to advantage with an established advertising company of wide experience. To be effective these agents must be kept well informed of local conditions so that the advertising matter may strike a responsive local chord.

Successful advertising will be characterized by effectively driving the subject matter home, breathing a spirit of reciprocity between the public and the company, and it should all be done with one end in view, to bring results. It is desirable to devise some clever phrase or symbol which can be used by the company in all its advertising matter so that the symbol alone whenever it appears will tell its little story. "At Your Service," "In the Public Service," "Light and Power," "Phoebe Snow and the Road of Anthracite," and similar phrases, become identified with the company itself and make a strong appeal to the public.

"House Organs." Many of the larger electric light companies publish bulletins, magazines or monthlies, house organs, as they are called, for regular distribution to their customers. Even the smaller companies might, with advantage, follow this example, covering the same field with a simple folder or pamphlet. This form of advertising makes a direct appeal to the customer, as it comes to him personally, and is usually sufficiently attractive in its make-up to secure his attention. Such a publication can be made the vehicle of keeping the customers advised of new developments in the company's facilities, and will keep the consumer advised of what his neighbors are doing to use the company's service in other parts of the town.

Electric Signs. The electric sign is, of course, one of the striking forms of advertising, and makes its appeal by literally burning itself into recognition. There appears to be no limit to the usefulness of the electric sign as an advertising medium, and the variety

of purposes for which it can be used is constantly increasing, and it should be borne in mind that in using signs the company is making application of its own product, and its signs should, therefore, be conspicuous for their brilliancy, good taste and high standard of maintenance.

We all know to what an extent this form of publicity is availed of in the "Great White Way" in New York City, a brilliant center which every large city here and in Europe is trying to duplicate, and it has its counterpart on a more modest scale, perhaps, in nearly every civic center of our country.

All of these various forms of business activity are organized and conducted by the public service corporations, not only for the purpose of extending their business and increasing their revenue, but as a plain duty to the public which has a right to be advised of improvements in the art as soon as they have been developed, so that the people may enjoy in their homes and at their places of business the conveniences and comforts which the splendid achievements of the electrical industry provides, and as soon as they are made commercially available.

Conclusion

In this very brief review, I have endeavored to give a general outline of the various elements which go to make up the commercial aspects of the electric lighting business. It has not been possible, within the limited space and time allotted for the presentation, to do more than furnish a "bird's-eye view," as it were, of the business features of the electric lighting industry, emphasizing those elements which may be of particular interest to the illuminating engineer.

The officers of the Illuminating Engineering Society are to be congratulated on their courageous initiative in organizing this course of lectures, and this great university is fortunate in having again made manifest the true university spirit in taking, among the higher institutions of learning, the first decisive step toward the recognition of the science and art of illuminating engineering as a branch of the engineering profession.

XVIII

THE COMMERCIAL ASPECTS OF GAS LIGHTING

By Walton Clark

CONTENTS

The subject assigned to me by the originators of this important course of lectures is "The Commercial Aspects of Gas Lighting." I take my subject, broadly, to involve a discussion of the commercial advantage to a community from the establishment and maintenance of a gas service; of the steps a community may wisely take to insure a service satisfactory to itself, and of the measures the supplier of gas may wisely take to the end that the service it renders may have the approval of its customers, and that it may receive the dividends that should be, and must be, the inducement and reward of such service. So taken, my subject can receive but inadequate treatment in an hour's talk.

A gas service, to be a commercial advantage to an individual or a community, must make possible the attainment of a desired end at a less cost than such end can be otherwise attained. In a consideration of this point, cost must not be taken as only a matter of direct payment of dollars and cents to the supplier. Convenience is a factor in the ultimate cost, as are also coincident effects, advantageous or otherwise, of the establishment of a gas plant, and the application of gas to domestic and industrial uses. To the extent that gas is capable of conserving the health or time of the consumer, it is of commercial advantage to him.

Good service costs more than poor service. Poor service may be dear at any price. I believe there will be no denial that it is to the commercial advantage of the consumer to pay somewhat to have the gas business of his town so ordered that he will have good service. The chief factors of good service to consumers and to community are continuity of supply; pressure adequate to insure the economical use of what gas-consuming appliance the customer may desire to operate; uniformity of pressure at any point; courteous, prompt and intelligent response to requests, and the anticipation of requests for information relative to gas and gas-consuming appliances; good and uniform quality of gas; extension of service to each district of the city supplied in which profitable business may be obtained. These factors of good service are not to be secured without expenditures on capital account, that will not be made unless assured a fair return; and on operating account, that cannot be made unless the price received is sufficient to justify them. A gas supplier cannot give good service unless adequately compensated, and cannot long prosper unless he give good service. Nowhere in the field of commerce is there a more real community of interest than with gas company and gas consumer. Neither realizes the best attainable result without that good service rendered and received which insures satisfaction to the user, and a willingness to pay the necessary price to insure its continuance.

For 70 years the inhabitants of the larger American cities have had such commercial advantage as comes from the maintenance of a gas service. Little knowing of the elaborate and painstaking preparation and continued care involved in the rendering of such service, they have rested in the knowledge that at any hour of any day they could command the fruit of such preparation and care; that at any moment, at a turn of the wrist and the lighting of a

match (and in recent years without the match), light and heat were at their command, and that as discoveries and improvements in the art of gas making and utilization were developed, the fruit thereof was theirs without asking or effort; that intelligent and trained men were in constant effort to discover or produce new uses for gas that should, by their convenience or economy, commend themselves to the housekeeper or manufacturer as practicable means of saving money or labor, or of improving product, and that, as improvement in methods and extension of use made possible, the selling price of gas would be correspondingly reduced.

This is all accomplished by progressive companies through an organization, in general, such as I now proceed to describe.

In an ideal organization there will be clear and direct lines of reporting and responsibility, from the subordinate, of whatever rank, to the president. There will be no doubt in the mind of any employee as to what his duties are, or to whom he is directly responsible for the proper performance of those duties. There will be no doubt on the part of any head of department as to what part of the business of the company is entrusted to his care, which of the subordinate employees are under his orders, and how far it is permitted him to act upon his own initiative and without immediate reference to his superior officer. Each head will recognize clearly the extent of his own responsibilities and privileges, and will direct his ambition and efforts to the accomplishment of the work entrusted to him, acting in confident and free co-operation with the other departments of his company, in such a manner as to best serve the public and the interests of his company, and to conserve the resources, material and human, entrusted to his use and direction. Misunderstandings by heads of departments on these points will surely lead to confusion, to discord and to ultimate harm to the company, the service and the public.

There is a difference of opinion among operators as to the exact detail of an ideal organization for operating companies. I cannot dogmatize on the subject. The organization must vary in its form with the size of the company, with its policy as to so-called "side lines"—as the treatment of residual products, the sale of burners and appliances—which, in turn, will be governed by its geographical location and the character of the population it serves. Also the general character and ability of the men who are most available for the operating positions, perhaps from having grown up in the

employ, must have an influence on the character of the organization. But there will be no disagreement as to the general principles involved, and as expressed above. A practicable and reasonable form of organization is, in general, as follows:

The responsible head of a gas company is the president. He is generally a man of affairs and of high standing in the community. He should be, and generally is, selected for his reputation for breadth, business acumen and probity. He is often without practical knowledge of the manufacture and distribution of gas. Always, when not technically familiar with the business of which he is the head, and often when he is, he has reporting to him an operating head, sometimes entitled "general manager" or "vice-president in charge of operation," to whom all the heads of the various operating departments in their turn report—this operating head being responsible to the president, as the president is to the board of directors, for the proper conduct of all the operations of the company. Reporting directly to the president are also the treasurer and, in part, the secretary; except that, in some companies, the president undertakes directly, and not through any of his subordinates, though generally with their co-operation, the settlement of such questions of a legal, financial or public policy character as may from time to time arise for solution.

The president of a large company will receive many letters, addressed to him either as president, or personally, and dealing with questions of service, supplies and processes, or bearing complaints of the conduct of officers or other employees, or asking for information. Such letters, in well-ordered companies, are referred directly to the operating head, to the treasurer or to the secretary, for investigation and report to the president. The referee uses his discretion whether to take the matter up with the head of the department concerned or otherwise. The president uses his discretion in determining whether the further correspondence with inquirer or complainant shall be with the officer to whom he has referred the matter.

The heads of departments reporting to the operating head are the engineer in charge of manufacture, whom I call for convenience engineer of works; the engineer in charge of distribution, whom I call for convenience engineer of distribution; the purchasing agent; the commercial agent; the claim agent, and the secretary—in so far as his duties relate to accounting, auditing, meter reading, etc.

The engineer of works is in charge of, and responsible to the operating head for, the construction and operation of the gas works, up to the outlet of the holder, whether this holder be located at the gas works or be a so-called "outlying holder." He is responsible for recommendations for new construction and for alterations; for changes in materials, apparatus or methods of manufacture, necessary or important to insure a continuity of supply, or the realization of economies in the handling of materials and in the manufacture and storage of gas, and the conservation and utilization of the residual products of manufacture; and for the discipline and contentment of the employees of his department, and the safety, order and sanitary condition of the gas works. To him report the superintendents of manufacturing and holder stations, the chemists, engineers and clerks connected with the manufacture and storage of gas. The engineer of works is of necessity a mechanical engineer with an extensive knowledge of industrial chemistry, for the processes involved in gas manufacture are chemical processes, while the structures are so important and diversified as to require in their design, erection and operation a high order of engineering knowledge.

The engineer of distribution is in charge of, and responsible to the operating head for, the laying and maintaining of mains and services, and setting of meters and house governors and such gratuitous work as is done for the consumer; for the setting of stoves and other gas-consuming appliances; for the conduct of the meter, service and appliance repair shops; for the maintenance of appliances; for the conduct of the general storeroom and stables; for the conduct of the street lamp lighting department; for the work of the illuminating engineers of the company, and the conduct of the experimental photometrical laboratory; and, generally, for the economical and efficient prosecution of all the work of the distribution system and gas-consuming appliances, from the holder outlets to the consumers' burners. He is held responsible for the maintenance of appliances on consumers' premises in so far as his employer may decide that this work be undertaken. This will include the maintenance of Welsbach burners, under agreement with the user, when the policy of the company comprehends such agreements. He is of necessity a mechanical engineer, with a knowledge of illuminating engineering.

The commercial agent, reporting to the operating head, is in charge of, and responsible for, the canvassers, the sellers of appliances, for advertising and for soliciting and obtaining new business.

The purchasing agent is responsible to the operating head for the purchase of all materials used, at proper prices, and upon the specifications of the head of the department using the materials. He approves bills for payment by the treasurer, upon the certificate of the department head, or his representative, that the materials have been received and are in quantity and quality in accordance with the specifications.

The claim agent has charge of, and is responsible to the operating head for, the settlement of claims for damage to person or property, asserted to have resulted from the operation of the company's plant, or the conduct of its business.

The secretary reports in part to the operating head and in part to the president. He reports to the president with reference to that part of his duties involving the custody of the records and contracts, and the certification of stock certificates—where this duty is not under the law assigned to the treasurer. He has charge of, and is responsible to the operating head for, the proper conduct of the accounting and auditing departments, the reading of meters and the keeping of the records.

The treasurer is an officer of the board, elected by it and reporting to the president as its representative. He is responsible for the collection of bills, the payment of bills, the custody of the funds, and for the banking and general financial matters incident to the conduct of the company's business.

Having set out, in general, the organization of an operating gas company (not a so-called "holding" company). I proceed to a brief statement of the methods of operation of some of the departments that come into contact with the consumer, or with the work in which he is especially interested.

It is of great importance to the consumer and the company that the employee in charge of the order and complaint desk should be competent and courteous. It is here that the consumer comes in most intimate contact with the company supplying him with gas; it is here that he comes for information in connection with his gas supply; that he gives in his complaints and leaves orders for work to be done.

Among the factors of good service that he has a right to demand, and that the company will find to its commercial advantage to accord, is courtesy, and it is at the order and complaint desk that he may most be influenced and benefited by courteous attention.

Quite as important to the stockholders, as money-making results in operation, is the profitable extension of business, and the conversion into dividends of money earned by engineering efficiency. Intelligence and courtesy, on the part of the employees who have contact with the public, are necessary to the preservation and extension of the business, and to the keeping of the earned money for the benefit of the stockholders, and from waste in law suits and loss in competition. Disaster to stockholders' interests may often be traced with certainty to a false idea of what is the honest and reasonable asserted due of a consumer, irritated over a grievance, real or fancied. Such a consumer—and he is not unlike other men suffering under a sense of injury, and hoping not to be satisfied without a vindication—is deserving of patient hearing and quiet explanation, and their interest in their employer's prosperity and their own dignity demand that, as far as gas operators are concerned in the matter, he receive it.

The responsible officials of the company, having reasonable regard for the interest of their stockholders and for their duty to the public, will have care in selecting men who come in contact with the public in whatever capacity, to see that they are men of intelligence, courtesy and of reasonably good address. They will protect the public from imposition on the part of so-called crooks, by so uniforming or badging their men that when asking admission to premises they may be at once recognized as employees of the gas company. They will see to it that each employee who enters the premises of consumers on the gas company's business is instructed not only as to the most efficient way of doing his work, but as to the way that will give least annoyance to the occupant of the premises; that pavements, lawns, carpets and walls may not be marred as the result of the gas man's work, and that his language shall not give offense.

It is of importance to the consumer that his order or complaint, having been received, shall be quickly transmitted to the proper department for attention and execution—a record being kept by the order and complaint clerk of such complaint or order—and a suitable system being provided for following the matter, to insure

that the order is executed, the complaint given attention and the completion of the matter reported and recorded. The record clerk should have custody of a card index upon which is kept the history of the orders and complaints emanating from each premise supplied, and he will enter upon the proper card, for future reference, the character of the order or complaint and the completion of the work called for by it.

Telephonic communication will be maintained between the order and complaint clerk and the shop from which the work called for by the order or complaint emanates, that all matters with which the order and complaint clerk has to do may be quickly followed up, upon inquiry from the consumer, or for other reasons.

A large company will find it to the commercial advantage of itself and its customers to maintain automobiles and motorcycles for the use of such of its employees, engineers, superintendents, inspectors and others, as frequently have to visit widely separated manufacturing stations, shops, laboratories, offices, and main and service gangs. Also, it will find it advantageous to equip a portion of its order and complaint men with bicycles and motorcycles, and it may prove advantageous to use auto trucks for its stove-setting and meter-setting gangs.

A night emergency service is necessarily maintained by a large gas company, and a well-organized distribution department will be able, through the use of telephones in foremen's houses, to put gangs of experienced men on the street, for emergency work, at very short notice. In aid of general good service an all-night telephone service will be maintained—an operator at some central point, who may be reached from any private or public telephone in the city, being in touch with all offices, storehouses, works, shops and officials, and thereby able to start the message that shall bring promptly to any point all authority and assistance necessary to cope with any emergency. This operator will have knowledge of any fire alarm and will notify the foreman nearest the fire, that men may be on the spot to remove threatened meters and turn off the gas where necessary.

A gas company finds it to the commercial advantage of itself and customers, and, incidentally, to the commercial advantage of the world, to maintain a chemical laboratory, with a competent chemist in charge. A large company may reasonably employ from six to a dozen chemists for its operations. There is work for them

in the daily testing of materials in daily use, the special testing of materials bought under specifications, the analysis and utilization of residual products, and in the general experimental and investigating work that a large and well-managed gas company would naturally undertake in its own interest.

One of the large companies of the United States maintains a chemical laboratory at each of its manufacturing stations, and a central chemical laboratory convenient to the offices of the company. There is no room for doubt that the establishment and maintenance of these laboratories tend to the commercial advantage of the company and of its consumers, and to the conservation of the resources of the nation.

A large gas company also will find it to the commercial advantage of itself and its patrons to maintain an "appliance-testing" laboratory, wherein gas cooking and heating stoves, and industrial appliances of all kinds, may be tested for economy, efficiency and durability, and approved or disapproved for sale, as the result justifies. A wisely ordered gas company will not, without protest to the consumer, set or supply at his order an appliance known not to be efficient and suitable to the economical accomplishment of the desired purpose, and will not connect appliances known to be unsafe in use. The salesmen will be instructed clearly on this point. The ability to sell an article the purchaser does not want or need is out of favor with a gas company—not by such methods has the great gas industry grown to its gigantic proportions.

The gas company's mechanical and chemical engineers properly may be expected to be generally conversant with the physical and chemical phenomena attendant on the use of their product for illuminating purposes. The measurement of the intrinsic brilliancy of a flame in a horizontal direction, when burned in a burner agreed upon by the representative of the State or municipality, and the gas company, while quite sufficient for the official determination of the quality of gas relative to a standard, is not a determination of the value that may be obtained in its most intelligent use.

The larger manufacturers of lamps, mantles, fixtures and burners, issue books containing valuable and accurate data upon illuminating problems, and compiled by illuminating engineers of experience. Gas companies receive these books without cost. Small

gas companies that cannot afford investigation and research in illuminating engineering can offer to their customers, through the information so acquired, advice that will greatly help to prevent unsatisfactory and uneconomical installations. But large companies, to maintain and improve their relative commercial importance in the face of modern competition, will be prepared to do more than this. They will maintain a force of engineers educated and equipped to solve any problem in illumination that may be brought to them by a prospective customer, or developed by the commercial agent in his efforts for new business, to the end that the gas sold may be used to the greatest possible commercial advantage of the purchaser and the least possible encouragement to the competitor. They will be prepared to protect their customers against the use of inferior methods of illumination by having available the results of exhaustive tests of illuminating appliances under all conditions of use. The companies will have all data, founded on intelligent experiment and research, that may be needed to refute incorrect statements regarding their product by ignorant or unfriendly critics; they will search diligently for new facts, or for the best application of known facts, by which the use of their product may advance the comfort, convenience and health of the customer, while protecting his eyesight and satisfying his aesthetic temperament.

To this end illuminating engineers and a photometrical laboratory are a necessary part of the equipment of a large gas company.

A description of the photometrical laboratory of The United Gas Improvement Company, in Philadelphia, has appeared in the proceedings of the Illuminating Engineering Society. To indicate the scope of this laboratory, I will mention a few of the more important instruments:

Calorimeters.

Bar photometers, from 60 inches to 50 feet in length, for measuring horizontal intensity.

Radial photometers, for measuring distribution.

Integrating spheres, for measuring total flux.

Bolometers, for measuring radiant heat.

Colorimeters, for analyzing colors.

Photographic instruments.

Microphotographic instruments.

Life-tests rooms.

Instruments for testing strength of mantles, etc.

Adjustable rooms, for studying the effect of reflection from variously colored and arranged surfaces.

Apparatus for supplying gas under pressure.

A workshop for producing any construction which is desired for test.

A laboratory as here described is a valuable aid toward the perfection of gas lamps. It enables the gas company usefully to co-operate with the manufacturer, placing it in position not only to criticize lamps from its experience with them in use, but to criticize with specific detail and positive suggestion for improvement. For illustration, a certain lamp, otherwise fulfilling its functions with satisfaction, may cause a roaring or hissing noise; another lamp, covering a useful field of service, may be handicapped because it cannot safely be turned down; a third may be criticized because it throws too little light into the upper hemisphere; still another, an outdoor arc lamp, may have a pilot light that fails in cold weather, or the lamp may not be wind-proof under some conditions. By the use of the laboratory the engineers are enabled to gain definite, detailed knowledge of the causes underlying these defects.

Illuminating engineering is, from the viewpoint of the gas engineer, still in its infancy; many problems are to be solved, many avenues of research are to be explored. This field of research will never be exhausted. The physical and physiological principles are reasonably well known. The physical and physiological effects have not been quantitively determined and tabulated in convenient form. Such information is essential to the illuminating engineer in his efforts to be commercially helpful to his employer and to the user of gas, and the illuminating laboratories of the gas companies will undertake its preparation. Many other special problems crowd in to be solved. The perfection of methods for lighting gas lamps from a distance; and the utilization of the convected energy of the burning gas, in the ventilation of apartments are among the fascinating and important problems now under way to solution. Much remains to be done in the study of important characteristics of gas lamps actually in use, including, determining the relative intrinsic brilliancy of such lamps when fitted with different types of standard glassware; which of these possible combinations may be safely and properly imposed in the direct line of

vision, and the relative effects of these combinations of lamps and glassware, when placed in apartments with walls of different colors. This class of facts regarding the lamps and glassware is of the utmost value to the gas company's salesman, and it is one of the functions of the illuminating laboratory to prepare and tabulate such information, to the continuing commercial good of customers and companies.

The companies' illuminating engineers do not confine their activities entirely to the laboratory. In the preparation of their data they will consult with ophthalmologists. They concern themselves in the application and installation of gas lamps to meet the needs of gas consumers. They advise the illuminating salesmen as required; they advise owners and architects regarding the amount and character of the illumination they need, and how best, and most beautifully and economically, to secure it; they check up the results of their calculations, and educate their judgment, by reading, with the portable illuminometer, the actual illumination obtained by the installations made; and they make a constant study of the physiological and aesthetic principles involved under the conditions arising in practice, and in general apply scientific knowledge and experience to the correct illumination of habitations and spaces, to the end that the customer's taste may be gratified; that the fashion of the day may be recognized; that eyesight may be preserved and the human and material energies of the world conserved.

A claim department is an important part of the organization of a large gas company. To it is assigned the care of all accident and damage cases involving the employee, the consumer or the public, and upon its course in handling these cases depends the good-will of many people.

In a properly ordered claim department's dealings with the public, fairness will be a ruling factor. It frequently will give a claimant the benefit of the doubt in disposing of a case. In the adjustment of cases, it will exert every effort to cause claimants to be friendly toward the company. The good standing and reputation of his employer with the public may be a strong aid to a claim agent in his efforts to make just settlements, and the wise claim agent will conserve it jealously.

Where the work of this department bears on accidents to employees it is again the company's spokesman. It treats with the

injured man frankly, and by showing that the company intends to be fair, gains and holds his good will. This aids in the avoidance of complications in the adjustment of cases, particularly those concerning ignorant employees. The wise claim agent will not despise the apparently small accidents and claims brought to his attention. Eternal vigilance is the price he must pay for a fair and just accident account.

The department will be in charge of a claim agent who has authority in the disposition of cases. He is aided by adjusters and investigators, in proportion to the extent of the operations of his employer.

When an accident occurs, or a claim is received, the man who has first information will report to his immediate superior, giving all immediately obtainable details. If the case prove serious, the details will be telephoned at once by the latter to the claim department, and in any event a full written report will promptly be made.

When the initial report of a case indicates the advisability of a settlement, the claim agent will give his representative a limit within which to secure a release. Where investigation only is required, or investigation and later settlement appear in order, the case will be discussed with the representative that he may understand the several points to be covered. After investigation, or if the case cannot be adjusted within the limit specified, the claim agent will prescribe the future course.

Should the department and the claimant finally fail to agree on a settlement, the case will be scrutinized again to make certain that no injustice is being done the claimant, and if so found, that all evidence available for use in court has been obtained. Later, when the suit is called in court, the company's attorneys will find it only necessary to conduct the trial, all evidence within reach having been previously placed at their command. The claim agent or his assistant will be present at the trial of a case, and pass upon any settlement proposition that may arise during trial.

The nature of the work of the members of the claim department familiarizes them with accident hazards, and from time to time, as these hazards may be observed by them, they will bring them to the attention of the proper officer.

The successful men in a claim department will be found inquisitive, shrewd, fair minded and possessing good judgment.

They will have constantly in mind that polite and painstaking attention must be accorded in each case, regardless of its merits.

The department of a gas company's business that has most increased in importance during recent years is the new business department, in charge of the commercial agent. The improvement in the wares of suppliers of other and competing sources of illumination has compelled gas companies to greater efforts to obtain and hold their illuminating trade.

The successful commercial agent will be an optimist, with a fully developed commercial sense, a sense that the aim of his department is not, unqualifiedly, to sell goods, but to sell goods with the least possible "over-head" charge, and not at all where the end would not, in profits, fully justify the means in dollars expended. He will be energetic, resourceful and diplomatic, and will have an organization capable of promptly and fully caring for all needs of the community, as far as they lie in his field of responsibility. He should have a knowledge of the principles underlying the use of gas in the appliances he sells.

The salesman will be trained never to misrepresent the quality of the article which he has for sale, and never to underestimate the cost of its use to the consumer.

Reporting to the commercial agent will be two subdepartments, each with specific duties, whose success is dependent upon their combined efforts. These subdepartments are the sales force and the advertising departments.

The employees in the sales force should embody the energy and optimism represented by the commercial agent. They will be salesmen, men who can convince the doubting public that they will benefit by the purchase of the appliances offered. There will be two classes of salesmen; first, general salesmen, and, second, specialists. The general salesmen will be equipped by experience to sell the general gas-consuming appliances for household use. These men will be instructed to keep in touch with all the consumers and non-consumers in the territory for which they are responsible. Each man will be assigned to a definite territory and held responsible for the results in his district. These salesmen are the class of employees of the company with whom the largest number of consumers come in most frequent contact; they will be imbued with a proper sense of their obligation to see that the gas company suffers no loss in reputation through their neglect.

There are branches of the gas sales business in which the work is much more complex than the sale of domestic appliances. These are the more intricate lighting propositions, such as arise in commercial and factory lighting, and the application of gas to industrial purposes. Such work requires special salesmen, with a knowledge of engineering.

The demonstration of appliances will be given attention. The consumer will want to see the appliance it is proposed to him to purchase in use under the conditions that will exist coincident with his use. It is, therefore, important that the company provide proper display rooms and outdoor spaces, conveniently located, in which the various appliances for indoor or outdoor use can be seen in actual operation. The demonstration will not end here, for the purchaser should be shown the proper and efficient way to operate the appliance after it has been installed. Demonstrators will be employed, capable of showing the consumer the method of operating his appliance to the best advantage on his own premises.

It will be found of value to the sales force to have a card index, showing the appliances in service with each consumer and the prospect of further sales. From this index the work of the salesmen can be guided. Also this index is of great value to the advertising department when sending out advertising matter. As the salesman reports his fair prospects on the card index, the advertising department will follow up these prospects with suitable advertising, bearing upon the appliance which the salesman is trying to sell, and mailed so as to reach the consumer between the visits of the salesman.

Advertising is a most important factor in the promotion of business when combined with an efficient selling force capable of following up the prospects which have been developed. It is, therefore, important that the advertising department be closely in touch with the sales force.

The advertisements will never over-state the merits of any appliance, or under-state its cost to purchase, to install or to operate. To do otherwise is to create a dissatisfaction with appliances, however meritorious, purchased under a misapprehension, and is to put a weapon of offense into the hands of a competitor.

We may safely claim that the operating force of a gas company are, in the best sense of the term, public servants. No industry, public service or otherwise, requires more self-sacrificing

devotion to the maintenance of continuous and good service than does the gas industry. Interruption of service is almost unknown, has grown through tradition to be considered a disgrace, and has been prevented only by the utmost care, intelligence and watchfulness. The gas business is a 24-hour 365-day industry. It has been truly said of the gas man that "his shift begins when he spits on his hands and ends when he gets through." For the conscientious operating man there are no hours for beginning and ending work. His life must be, and is, devoted to the service of his company and of the public.

This exacting service has proved attractive to men of the highest class, and men of the best antecedents and education, including graduates of technical schools, colleges and the military academics, will be found on the list of successful and rising operators of the American gas industry. The position held by gas managers in the business and social life of their communities is a spur to the ambition of all gas workers.

The results of the efforts of the gas company employees to improve methods and quality and to increase sales, by the extension of the use of gas, have been remarkable changes in quality and price.

From the standpoint of the community and the consumer, the most noteworthy changes in the conditions surrounding the gas supply in the past generation have been the reduction in the price and the extension of the use of gas for fuel purposes. These have come coincidently, and each has profoundly affected the other. When gas-consuming fuel appliances became practicable for domestic use by people who thought more of convenience than of economy, and for such industrial purposes as could afford the higher charge of fuel per unit of product, because of greater certainty of character and quantity of product, the output of gas, due to its application to these purposes, was materially increased, giving an opportunity for a further reduction in price. With the reduced price came a wider field of use, both as a heating and an illuminating agent, and there followed an opportunity for further reduction in price. These two causes acting on each other have been largely instrumental in effecting a reduction in the average price per 1000 cubic feet of gas in the United States from about \$3.00 in 1875 to about \$1.00 in 1910. These figures closely ap-

proximate the truth, and are based on the most reliable data obtainable at this time.

At present prices, gas is available for people of large or small means, with a great improvement in the social condition, particularly of people whose women folks do the ordinary work of the house—employing servants, if at all, but occasionally, and for the heavier work. It is probable that to-day the greatest commercial and social advantage to a community, from the use of gas, results from its application to domestic purposes other than lighting, and that through this application has come a measure of amelioration in the condition of the wives of men of moderate means not exceeded by any improvement achieved in our generation. That this is a commercial advantage to the community needs no demonstration. It has come mainly through the painstaking and persistent insistance of the gas companies that their customers use gas for cooking and heating, as well as for illuminating.

From the standpoint of the engineer and operator, the most remarkable changes in the conditions surrounding gas production and supply, during the past generation, and affecting the commercial status of supplier and supplied, have been the introduction of water gas and the development of the Welsbach incandescent gas burner—the former resulting in improvement in quality, reduction in cost and simplification of production; the latter resulting in increasing the useful illuminating result from the consumption of a unit volume of gas, and in a greater adaptability to decorative purposes.

The average candle-power of gas sold in the United States in 1875—as far as the inadequate records of that day show—was 15, and the candle-power of the manufactured gas being supplied in 1910 is probably 22. From these estimates are purposely omitted Pintsch gas and acetylene gas. The figures apply, therefore, to the great bulk of the gas produced for distribution and sale to individual consumers.

There has been a curious and noteworthy coincidence concerning the competition between gas and electric light. In the early days of electric lighting, water gas, varying from 22 to 30 candle-power, was a noteworthy competitor. The improvements in the electric lamp in the early years of its use threatened the illuminating-gas business seriously. Then came the Welsbach burner,

which re-established the ascendency of gas. Later came the tungsten lamp, which seemed again to threaten the gas industry. Almost coincidently came the so-called "reflex" burner, or the inverted Welsbach, with so-called automatic lighting devices, which maintains gas at least on a par with electricity in the competition for the lighting business of the world.

It is very fortunate for the consumer that these coincidences have existed—insuring him a choice between two brilliant sources of illumination, each served to him without trouble to him—each served on demand, each possessing characteristics insuring him reasonable satisfaction in its use, and each possessing certain advantages over the other. As he values these advantages the seeker after light will decide for one or the other illuminating agent.

The gas business is a natural monopoly. In the light of experience, no argument can be advanced for the presence of two gas companies in the same territory. Competition in gas has been tried as a remedy for asserted unfairness in price, quality, or other factor of service, and always with the same result—a combination or elimination—that left one company in the enjoyment (often questionable in its degree) of a monopoly of the supply, though generally with duplication of apparatus, involving duplication of capital investment, upon which interest is to be earned. All authorities on political economy now agree that the gas supply should be a monopoly. No community will reasonably grant a monopoly franchise without regulatory conditions. In some localities this matter is covered by general laws, and the regulations are left to a so-called public service commission, given power to fix rates, authorize the issuance of securities, and generally to regulate the affairs of gas companies, in so far as they affect their relations to their consumers. In other localities, as illustrated in Philadelphia, the conditions of service, quality, price, etc., are set out in the contract granting the right to occupy the streets and to conduct the business, and thereafter the relations between the gas supplier and the city are limited to the supervision necessary to determine that the company is living up to its preimposed obligations.

There is no doubt that public service corporations, in the enjoyment of a monopoly, should be subject to regulation, supervision and protection. There is serious doubt whether a so-called public service commission is a better means of protecting the public from poor service or overcharges, and the companies from destructive

competition and irresponsible attacks, than is an agreement between the company and the community, made at the time of the granting of the franchise, or later. Constitutional delegates and legislators, when considering this question, should have in mind the great importance of guarding the community and the company against the temptations that come to a company, and to public officials, having under their control and at their dictation such great interests as those involved in public service work.

Gas, as a rule, has been sold at a price "per 1000 cubic feet"—the quality being sometimes stated in the original agreement between the community and the company. Charges based only on a certain and uniform rate per 1000 cubic feet put the burden of supply of gas to the consumer of small quantities somewhat upon the shoulders of the user of gas in large quantities. To illustrate: A meter being set for the supply of gas may be used only to measure gas that is required in the emergency of the failure of other sources of illumination. It may be seldom in use, though always in place ready for use. There are many instances of this kind in every large city. The gas company, and through it, the consumers of gas in paying quantities, bears the burden of the investment in this meter and in the service connecting it, and in the apparatus at the works held in reserve for the gas consumed through this meter at the infrequent times that such supply is required. To correct in part the inequality of this practice, many companies have adopted a scale of prices based on the consumption, and this has had the approval of the several State commissions.

Another suggested method of charging, somewhat in use among electric companies, is to make a fixed charge against each consumer, based on the necessity of supplying and maintaining manufacturing and distributing plant ready to serve him when using at his possible maximum rate, whether or not he use the gas thus made available to his demand, and then charging each consumer the same rate per 1000 cubic feet of gas consumed. This is treating everyone fairly, giving the larger user all the saving of investment and cost of operation due to the larger sales through one service and meter.

The purpose of this method of charging is not to bring to the company a greater gross or net revenue than it would receive on the first method of charging, but to equitably apportion among consumers the burden of maintaining the gas supply.

A method of determining the charge per 1000 cubic feet, whatever system for the division of the burden among consumers may be adopted, is known as the "sliding scale." It was adopted in London 35 years ago and has worked satisfactorily since.

It has been in service also in Boston, but for too brief a time to prove finally its value in that situation.

At the time of adopting this so-called "sliding-scale" system in London a standard price for gas was established, and with it a standard rate of dividend, each being at the time determined as fair to the company and to the consumer. It was coincidently provided that each reduction in the price of gas of a given amount should carry with it the right on the part of the company to declare a certain higher rate of dividend, if the same be earned; while an increase in the price of gas to the consumer was to be followed by a rate of dividend lower than the standard; that no new stock was to be issued except for funds for the extension or improvement of plant, and that all new stock was to be sold at auction. This system insures that new capital shall be obtained on such a rate of dividend as financial conditions and the confidence of the public in the gas business will permit at the date of the issuance of such capital.

The city and citizens of London, and the gas companies supplying them, have arrived at their present generally satisfactory relation by a most devious and unsatisfactory course. Competition has been tried and all its inconveniences and wastes amply proven. There were temporary reductions in the price, followed by combinations between the companies, with division of territory, then a reduction in the number of companies by combinations and eliminations.

As a result of these eliminations, combinations and resulting monopoly under the "sliding scale" the price of gas in London has steadily fallen; and while the quality is not what we in America are accustomed to regard as high, and the price has not in the past been as low as would have been possible had there been no unnecessary duplication of plant, it has proven generally satisfactory to the people, and to the very eminent governmental commissions which from time to time have been appointed to investigate the subject.

One of the serious objections to the use of gas by a consumer of small means, has been the lack of certainty as to what amount per

month he will be called upon to pay for his illumination. It is difficult to economize in the use of material or energy that is supplied as wanted without knowledge of the quantity being taken, and that may be used at will by any member of the household. To meet this difficulty and objection, the so-called "prepayment" meter has been devised. Using this prepayment meter, a consumer may buy 25 cents' worth of gas as he would buy 25 cents' worth of milk or potatoes, or other commodity, making payment in advance and receiving warning when the 25 cents' worth has been nearly exhausted, and then determining whether or not to buy a further quantity. This type of meter has been in general use 10 or 12 years, and there are hundreds of thousands of them in use to-day, no doubt, to the commercial advantage of many of their users.

The consumer using a prepayment meter does not have to give his time to going to an office to pay his bill, and the company has the advantage of certainty of payment for this part of its product. There are, however, objections, in part, if not fully, neutralizing this advantage to the company. The commercial advantage is mainly or altogether with the consumer.

This consideration of the relation of the gas company to the consumer and to the community leads naturally to a consideration of the sometimes advocated system of public ownership and operation of gas plants.

The framers of constitutions and statutes for civilized communities have provided the necessary legal machinery to enable the citizen to procure the advantage of such forms of public service as are commercially possible under the communal conditions surrounding him, and as are useful to him and conserving of his energy.

The first question to be settled by a community desiring the commercial benefits to follow the establishment of a gas plant, and so circumstanced that an economically managed gas undertaking may reasonably be expected to prove profitable, is, necessarily, whether to conduct the business as a community or to invite private capital and enterprise into the field. The latter course has been adopted by all but a few American municipalities. Several years ago there was a strong agitation in the United States for the municipalization of gas plants. As a result of this agitation, the National Civic Federation appointed a commission to investigate

the municipalized public utilities in this country and in Great Britain. The most widely known American advocates of municipalization and a few outspoken opponents were on this commission. The members appreciated that in this country it had been generally accepted that such classes of public service as had to do with protection from violence, the preservation of health and the securing of justice were unquestionably and properly the immediate care of the State, and not to be delegated to individual control, natural or State created, and not to be provided at a price, and that common American practice left to individual or corporate enterprise the provision of such public service as is rendered for a price, and properly regarded as a commercial venture.

The commission, limited in opportunity in America, made an exhaustive examination and comparison of municipally and privately operated gas plants in Great Britain. With its corps of engineering, accounting and sociological experts it visited and examined the municipally operated and oft-instanced plants at Glasgow, Manchester, Leicester and Birmingham—comparing them with the company-owned plants at Liverpool, Newcastle, Sheffield and London.

The commercial advantage of a gas service is not measured alone by the price of 1000 cubic feet paid by a consumer. Important as is price, there are other considerations as nearly affecting the consumer's commercial interest. Quality of commodity and character of service are of the first importance. Attention to his wants and complaints, suggestion of conservation of his means and convenience, uniformity in conditions of supply, each an element in character of service, may be as important to the commercial interest of the consumer and the community as price. Let us refer to and quote from the reports of the experts of the commission, to learn how price and these other important elements are affected by municipal operation, as far as the commission was able to discover.

The lowest reported candle-power at center of consumption is from a municipal plant, and is 15 per cent lower than the lowest supplied by a private company. The highest candle-power gas is from a company plant, and is 27 per cent higher than the highest municipally served gas. The highest cost of a unit candle-power flame for unit time is in a municipally supplied town, and is 18 per cent higher than the highest cost in a company-supplied town.

The lowest cost is in a company-supplied town, and is 35 per cent less than the lowest cost in a municipally supplied town.

(See Part 1, Vol. 1, page 315, *et seq.*, of Report National Civic Federation, 1907.)

Referring to the attention given to the consumers' wants and complaints, the experts say (page 322):

" One of the subjects examined by us in considerable detail was the system of handling consumers' complaints in use by the various undertakings. The methods employed by both the municipal and private undertakings were good, but the private companies in all cases were somewhat better equipped and were more systematic in checking up quickly the nature of the complaint and seeing that it was quickly attended to, paying particular attention to the wants of the consumer."

Referring to the efforts of municipalities and companies to promote the use of gas for purposes other than illumination, thereby helping the consumer to economy of means and energy, the experts say (page 329):

" Summarizing the foregoing, the conclusion arrived at is that whilst gas appliances of every kind may be obtained from either the municipalities or the companies, the latter show greater enterprise in pushing their use amongst gas consumers."

Referring to the broad question of the conservation of the interests of community and individual, we raise the question of cost of gas to the consumer relative to the cost of the raw material of manufacture and of labor.

The factors beyond the control of the management, and having the greatest influence on the difference in the cost of making gas in the British cities, as far as the investigation developed, are that part of the cost of gas-generating materials due to location of plant (freight differences) and the gas-producing quality of these materials. We have been able to make a comparison in which this difference in the cost of materials and in the amount of gas produced per unit of material has no effect, and which shows each municipality to yield results far inferior to the results of each company.

I make a statement of the losses that would have been suffered by the municipally owned gas undertakings if selling gas at the price charged by the Sheffield company and buying gas-generating materials and labor at the Sheffield company's cost per 1000 cubic

feet of gas made. The figures would have been on the same side of the ledger, but different in amount, if the comparison had been with any other of the companies investigated.

The selling price of the most important residual—coke—has little influence on this part of our problem, except as indicating the character of management, for it will naturally, other things being equal, follow the price of its competitor—coal.

Reading the supplemental report of the engineers, we find therein a statement that the companies in general purchased to better advantage than the municipalities. We know, from the reports of the experts, that the companies' plants were, in general, more skilfully operated than were the plants of the municipalities. But, ignoring these two facts, we still find that each municipality whose plant was investigated, if paying the same price for gas-generating materials per 1000 cubic feet of gas made, as each of the companies (which assumption eliminates differences in price and gas-producing properties of the materials), and charging the same price for gas as each of the companies, would, on its reported sales and on its own accounting, have lost money on its operations in the year 1905—the period covered by the investigation.

The Birmingham municipality claimed $249,386 net profits from the operation of its gas works in the year 1905, after putting $181,907 into its sinking fund. If it had sold its gas at the prices charged by the Sheffield company, which operated at a satisfactory profit, and had the advantage of Sheffield's materials costs per 1000 cubic feet of gas made, it would have made no profit, put nothing into its sinking fund, and have lost $86,897 by the year's operations.

The Leicester municipality claimed $210,380 net profits from the operation of its gas works in the year 1905, and put into its sinking fund $70,311. If Leicester had sold gas at the Sheffield company's prices, and had the advantage of Sheffield's materials costs per 1000 cubic feet of gas made, it would have made no profit, put nothing into its sinking fund, and have lost $7,289.

The Glasgow municipality admits a loss of $58,346 from the operation of its works in the year 1905, and put into its sinking fund $153,593. If Glasgow had sold its gas at the Sheffield company's prices, and had the advantage of Sheffield's materials costs per 1000 cubic feet of gas made, it would have made no profit, put nothing into its sinking fund, and would have lost $75,175.

The Manchester municipality claimed a net profit of $298,212 from the operation of its gas works in the year 1905, and put into its sinking fund $212,060. If Manchester had sold gas at the Sheffield company's prices, and had the advantage of the Sheffield company's materials costs per 1000 cubic feet of gas made, it would have made no profit, put nothing into its sinking fund, and have lost $73,984.

It may be claimed that the difference in labor costs should be included in these comparisons, and we now study their effect on our figures.

It is to be remembered that the Sheffield company is, with the exception of the Leicester municipality, the smallest gas supplier investigated, and has the smallest sales of gas. Therefore, the municipalities, with equal efficiency in management, and at Sheffield's prices for gas and cost of gas-generating materials and labor, would have produced results at least equal to those produced in Sheffield; and we are, therefore, compelled to charge the loss they would have sustained under Sheffield's conditions to mistakes in design and policy and inefficiency in management, or to overcapitalization, each as compared with the Sheffield company.

The differences in labor costs are due to differences in local labor rates and in operating efficiency. They are referred to here simply to avoid the possible criticism that the prices paid labor might have had an effect in so increasing the cost of gas to consumers as to nullify the force of our comparison. Had we included in these comparisons the differences in labor costs per 1000 cubic feet of gas made, as far as we find them set out in the schedules—which differences are due, in part, to differences in rates of wages, and, in greater part, to differences in efficiency of plant and operation—we would have had the actual losses sustained by these municipalities at the Sheffield company's prices of gas and costs of gas-generating materials and labor, as follows:

Birmingham municipality's loss	$227,770
Leicester municipality's loss	75,644
Glasgow municipality's loss	96,790
Manchester municipality's loss	168,384

And of them only Manchester and Glasgow (like the other municipalities, making no profit) could have put anything into their sinking funds. Manchester could have put into this fund only

$43,676, showing no profit, though it claimed a sinking fund and profit combined of $510,272, and Glasgow could have put into this fund $56,802, though it claims a sinking fund of $151,593 and admits a loss of $58,346.

Birmingham would not have earned any profit, and would not have come within $45,864 of being able to put one penny into its sinking fund.

Leicester would not have earned any profit, and would not have come within $5,334 of being able to put one penny into its sinking fund.

Clearly there is no commercial advantage to either consumer or community derived from the municipal operation of gas plants as illustrated in these British cities.

There are but 14 municipally operated gas works in American towns of 10,000 inhabitants or over, and but 5 in towns of 25,000 or over. It was designed to make a thorough investigation of the physical and financial conditions of the gas undertakings in two of these towns, Richmond, Va. and Wheeling, W. Va., selected by the advocates of municipal ownership on the commission as models illustrative of the advantage of the system they supported. The Richmond authorities objecting to the proposed investigation, the labors of the commission, as far as applied to municipally operated gas plants in America, were confined to Wheeling. This plant was compared with the company-operated plants at Atlanta and Norfolk. The Philadelphia gas works having been previously under municipal operation, and being at the time of the investigation under company operation, the comparison was of the two periods.

Wheeling was reported to have an inadequate, inefficient, largely obsolete plant—with poor discipline and poor service. To keep the plant in commission at all the city was refusing to permit the sale of natural gas for illumination. From the consumers' point of view Atlanta and Norfolk were superior in every respect except nominal price. Wheeling gas sells for 75 cents per 1000 cubic feet. Atlanta and Norfolk companies charge $1.00 per 1000 cubic feet; but what with charges for services and meter setting, the admixture of 15-cent 8-candle-power natural gas, insufficient and irregular pressure, and general inefficiency in every department coming in contact with the consumer, Wheeling gas is a dear commodity at any price.

From the point of view of the municipality there is even less reason for approval of Wheeling's venture. Prof. John H. Gray, one of the experts of the commission, reports of Wheeling: "The management is honeycombed with politics; appointments are parcelled out and controlled by councilmen. Should the political party in power change it is probable that the whole force in the department would be changed. All employees are regularly assessed for campaign expenses. Everybody acknowledges the condition is bad because of rotten politics. The public seems to be hopeless in regard to improving conditions." He makes no criticism of Atlanta or Norfolk's political or operating conditions.

The most convincing arraignment of municipal operation known to me is by Prof. Rowe, of the University of Pennsylvania. Prof. Rowe had opposed the change from municipal to company operation; but, after witnessing 9 years of the latter, he writes a report on the situation, from which we gather the following facts:

Dr. Rowe, commenting on the illuminating power of the gas for the first period, indicates that it averaged about 19 candles during the period. The gas at that time was tested through an Argand burner calculated to develop its highest obtainable illuminating power. If this gas had been tested as the gas supplied by the company now operating the plant is tested, it would have shown approximately 17.9 candle-power. This was from the works producing coal and water gas; the gas from the other works was below 14 candles; hence 16 is a liberal figure for the average candle-power of the gas in Philadelphia during the later years of municipal operation. And this is the figure to be compared with 22-candle-power gas now supplied to the citizens of Philadelphia.

Dr. Rowe further says: "Just complaints against the quality of the gas delivered constantly increased during the period of municipal operation."

Dr. Rowe having stated the service under municipal management to be "increasingly poor," speaks of the service under private management as follows:

"The gas service since the beginning of the lease has been such as fully to satisfy the demands of public opinion. Even the most prejudiced critic must agree that the officials of The United Gas Improvement Company have done everything in their power to improve the service in every respect. Complaints are given prompt attention and adjusted in a spirit of fairness."

Speaking of the attitude of the public toward the proposition to end municipal operation, Dr. Rowe says:

"It is true that no strong public opposition developed, due largely to the fact that the people had become wearied with the inadequate gas service, and looked upon the leasing proposition as a possible means of relief."

Dr. Rowe shows the city to have lost $981,593.30 during the last 4 years of municipal operation—$245,398.32 per year, the price of gas being $1.00 per 1000 cubic feet. He also shows the city to have received in cash from the operating company, during 8 years of private operation, $3,933,398.61, or $491,674.83 per year—a net gain in cash to the city of an average of $737,000 per annum. The advantage to the consumer who pays $1.00 per 1000 cubic feet of gas, the price charged by the city, comes from the increase of 37 per cent in the amount of light obtainable, all the improvement in service which Dr. Rowe credits to the private operation, the introduction of 180,000 gas-cooking stoves without charge for connection, the expenditure of approximately $2,000,000 in gratuitous work in the direct interest of the individual consumer. Dr. Rowe also says:

"As has been shown (under municipal management), there were abuses in almost every branch of the operation. The purchase of coal and the residual products were each under the control of favored individuals; the wages account was padded with incompetents, the friends of men prominent in city politics.

"It is unquestioned that there were leaks in management of the gas works at other points than the distributing system; it is true that the labor account was debauched, and it is certain that in the purchase and sales departments there were influences at work which worked harm to the city's interests. But the loss through such sources was inconsiderable when compared with those inflicted by councils by the senseless blocking of the way to improvement in cutting off the appropriations for modernizing the plant. During the entire period of municipal operation the officers in charge were engaged in a losing fight to preserve the works from ruin. There never was a time during the entire period that it could truly be said that the works were in an efficient condition."

Clearly there is no commercial advantage derived from the municipal operation of gas plants as illustrated in these American cities.

The commission made two reports—a majority report, signed by all the members but one, and a minority report signed by one member.

Briefly stated, the majority report of the commission, written after a systematic investigation of the effect of municipal operation of gas, electric and street railway industries in the well-governed cities of Great Britain, contains no statement or claim that the municipal ownership and operation of these industries has ever commercially or otherwise benefited any citizen or community or anywhere offered a success to be emulated or an example to be followed. It makes no prophecy that under any existing or createable conditions it will ever be commercially successful. It dwells upon the difficulties and dangers attending municipal ownership, particularly in America. It states public opinion in British cities operating trading industries to be unsympathetic. It advocates the regulation of public service companies. It is signed by each of the heretofore advocates of municipal ownership in the membership of the committee.

The minority report advocates company ownership and operation and governmental regulation of public utilities.

The commission making the above reports was one of the most important ever sent on a public duty of this character. It was adequately provided with funds; it had the entrée, practically, to every works, office or official circle where, in its judgment, it could obtain information upon the subject it was investigating; in its membership were men qualified for the work in hand, and determined that neither time nor pains should be spared in the efforts to obtain and present the facts necessary to enlighten the American public on this very important question. There can be no doubt in the mind of anyone familiar with the work and report of the commission that the question I have here considered—Whether it is to the commercial advantage of municipalities and individuals that the gas supply should be undertaken by the municipality—is correctly answered in the negative.

I have given more time and space to this branch of my subject than to any other, and for the reason that the question considered is the most important that I have to discuss before you. It is the first a community must consider in determining how best to insure to itself a commercial advantage from the introduction of gas service.

It is a part of my duty to present, as accurately as I am able, the extent of the gas business in the United States. I shall confine myself in this presentation to such gas as is distributed and sold, and not including gas made for industrial or illuminating purposes upon the premises where used, or natural gas produced by the user or produced and sold for large industrial purposes.

According to what are recognized as the best authorities obtainable, the consumption of distributed gas in 1909, for illuminating, cooking and small heating and power purposes, was 335,000,000,000 cubic feet, of which 160,000,000,000 cubic feet was coal gas and water gas, sold either separate or mixed, 23,000,000 cubic feet was acetylene gas, 166,000,000 cubic feet so-called gasoline gas, and 175,000,000,000 cubic feet natural gas.

I am fairly certain of the very close accuracy of all these figures, except the acetylene and gasoline figures, which are probably somewhat in error.

In order to present an adequate idea of the amount of gas used for illuminating purposes, I make the following table, which is based upon estimates that have been very carefully considered and compared, and which I believe to be nearly exact:

AMOUNT OF GAS DISTRIBUTED BY COMPANIES AND USED FOR ILLUMINATING PURPOSES

40% of water, coal and oil gas	64,000,000,000 cu. ft.
98% of acetylene gas	22,540,000 cu. ft.
92% of gasoline gas	152,720,000 cu. ft.
10% of natural gas	17,500,000,000 cu. ft.

The future of the gas business is promising. All the knowledge obtainable, with reference to the coal and oil deposits of the United States, indicate that for generations there will be no lack in gas-making material. The quantity of oil in the earth cannot be determined with accuracy, or even more than guessed at; but the discovery of new fields, scattered over immense and widely separated areas, indicates that there are large volumes of oil underlying the soil of the United States, enough for the uses of the country for generations. But if oil fails, and the manufacture of water gas is given up, there still remain the enormous deposits of coal, from which a satisfactory grade of gas may be made. To illustrate how large this volume of coal is, it is necessary only to state that in 1908, in the territory of the United States, there were known

and measured coal fields containing two hundred times as much coal as has been mined from the discovery of coal in America to that date. There will be no shortage of raw material.

There is wide room for improvement in the efficiency of incandescent gas burners, though less for improvement in their beauty or applicability. The modern incandescent gas lamp, its light emanating from an unfluctuating source of relatively large area per unit of emanation, alike applicable and suitable for the street, the workroom or the library; undazzling to the pedestrian or the driver, unwearying to the eyes of the worker and the student; so cheap that it is the night light of the economical; is yet so uneconomical of energy that less than 3 per cent of the radiant energy applied to it appears as illumination. It is to this opportunity for improvement in the illuminating efficiency of gas burners that the world must look most hopefully for an increased commercial advantage from the availability of a gas supply. Prices per unit of volume, or of heating value, are down almost or quite to their possible minimum. The cost per unit of illumination secured is far from its possible minimum, and mainly therein lies the confident hope and expectation of gas suppliers for the great extension of the illuminating trade they are now holding on the present merits of their product and of the instruments of its utilization.

LISTS OF EXPERIMENTS IN CONNECTION WITH A COURSE OF LECTURES ON ILLUMINATING ENGINEERING

Preliminary Experiments

1. Focal length of lenses and mirrors.
   Ames and Bliss, Manual of Experiments in Physics.
2. Intrinsic brilliancy of an image.
3. Adjustment of spectrometer.
   Ames and Bliss, *loc. cit.*
4. Dispersion curve of prism.
   Mann's Manual of Advanced Optics.
5. Dispersion curve of grating.
   Mann, *loc. cit.*
6. Spectrum analysis.
   Baly's Spectroscopy.
7. Radiometer or thermopile or bolometer—Spectroscope.
   Kayser, Handbuch der Spektroskopie, Vol. I.
8. Transmission curves of glass, water, quartz, fluorite, Ni $(NO_3)_2$ solution.
9. Energy curve of black body.
10. Simultaneous measurement of temperature with:
    (a) Thermo-couple.
    (b) Optical pyrometer (Wien's law).
    (c) Féry pyrometer (Stefan-Boltzmann law).
    Waidner and Burgess, Bulletin Bureau of Standards, Vol. I, p. 189.
11. Energy and visibility curves of commercial sources:
    (a) Incandescent lamps.
    (b) Welsbach lamp.
    (c) Mercury arc.

STANDARD PHOTOMETER BENCH

A. Measurement of candle-power of incandescent lamp in one direction against a standard.

Apparatus used, a Reichsanstalt model precision photometer.

Details of several methods of using a photometer bench; the use of different scales, centimeter, inverse square, direct reading. Procedures to secure accuracy, such as reversal of screen and substitution method. The use of various devices to equalize illumination, such as sector discs and absorbing screens. Methods of calculating results.

Liebenthal, Praktische Photometrie.

Stine, Photometrical Measurements.

Hyde, E. P., Bulletin of the Bureau of Standards, Vol. 2, p. 1. "Talbot's Law as Applied to the Rotating Sectored Disk."

B. Comparison of different photometers for accuracy under different conditions. The Bunsen, the Lummer-Brodhun equality and contrast, the flicker photometer. Comparison of these methods where the illuminants are of different colors.

Kennelly, "Photometric Precision," Elec. World, Vol. 21, pp. 1104, 1152.

Dow, J. S., Phil. Mag., Aug., 1906. "Color Phenomena in Photometry."

Ives, Herbert E., Trans. Ill. Eng. Soc., Nov., 1910. "Spectral Luminosity Curves by Flicker and Equality of Brightness Photometers."

C. Measurement of mean horizontal candle-power by point-to-point and rotating-lamp methods.

Liebenthal, Praktische Photometrie.

Stine, Photometrical Measurements.

Hyde & Cady, Bul. of Bur. of Standards, Vol. 2, p. 415. "On the Determination of the Mean Horizontal Intensity of Incandescent Lamps by the Rotating Lamp Method." Also Vol. 3, p. 357.

D. Study of the characteristic performance of different incandescent lamps—candle-power, voltage and current relations.

Liebenthal, Praktische Photometrie.

Stine, Photometrical Measurements.

Cady, F. E., "The Relation between Candle-Power and Voltage of Different Types of Incandescent Lamps." Trans. Ill. Eng. Soc., Oct., 1908, p. 459.

E. Measurement of efficiency by watts-per-candle meter.

Apparatus used, a commercial photometer bench with candle-power scale, fitted with a watts-per-candle meter.

Hyde and Brooks, Bul. of the Bur. of Standards, Vol. 2, p. 145.

Ives, Herbert E., Bul. of Bur. of Standards, Vol. 5, No. 4.

Paulus, C., "Ein neues Photometer." Elek. Zeit., 1908, p. 166.

GAS CHARACTERISTICS

A. Determination of specific gravity of gases used in the production of light.

Apparatus used, effusion test.

Butterfield, "Gas Manufacture and Assay of By-Products."

B. Determination of the calorific value of gas.

Apparatus used, calorimeter of the Junker type.

Proc. of the Amer. Gas Inst., Vol. 3, 1908.

FLAME STANDARDS

A. Practical use of a 10-candle-power pentane lamp.

"Notification of the Metropolitan Gas Referees," London, 1898.

Jour. of the Franklin Inst., March, 1908.

Trans. of the Illum. Eng. Soc., Nov., 1910, paper by E. B. Rosa and E. C. Crittenden.

B. Use of the Hefner amyl-acetate standard lamp.

Stine, Photometrical Measurements.

Rosa and Crittenden, Trans. Illum. Eng. Soc., Nov., 1910.

C. Use of standard candles.

Amer. Gas Institute, "Catechism of Central Station Gas Engineering in the United States," 1909.

Jour. of the Franklin Inst., Vol. CLXV, Nov., 1908.

D. Use of the Elliott standard lamp.

Trans. of the Illum. Eng. Soc., 1908.

Jour. of the Franklin Inst., Vol. CLXV, March, 1908.

STANDARD BAR PHOTOMETER

A. Determination of candle-power in one direction of flat-flame, Argand or mantle burner against the standard pentane lamp. Determination of mean horizontal candle-power by revolving sources of light.

Proc. of the Amer. Gas Inst., Vol. 2, 1907. Report of Com. on Methods of Taking Candle-Power of Gas.

RADIAL PHOTOMETER

A. Determination of the distribution of light from a given source; plotting of same on proper data sheets and the calculation of mean upper hemispherical, lower hemispherical and spherical candle-power.

Apparatus used, a three-mirror rotator.

Macbeth Illumination Sheets, Norman Macbeth.
Dibden, W. J., Practical Photometry.
Stine, Photometrica. Measurements.
Lansingh, V. R., Proc. Western Gas Association, May, 1906.
Woodwell, J. E., Vol. I, Trans. Ill. Eng. Soc., p. 248.

INTEGRATING PHOTOMETERS

Apparatus used, an integrating sphere.

A. Standardization of apparatus.
Means of testing for accuracy.
Precautions to be observed in use.

B. Measurement of total flux or mean spherical candle-power.

C. Measurement of mean hemispherical candle-power.

D. Determination of spherical reduction factors (in combination with mean horizontal candle-power measurements by standard bench).

Ulbricht, Elek. Zeitsch., Vol. 21, p. 595, 1900.
Ulbricht, Elek. Zeitsch., Vol. 26, p. 512, 1905.
Ulbricht, Elek. Zeitsch., Vol. 27, p. 50, 1906.
Sharp and Millar, Trans. Illum. Eng. Soc., Vol. 3, p. 502, 1908.

ILLUMINATION PHOTOMETERS

Apparatus used, Sharp-Millar and Bechstein photometers.

A. Standardization of apparatus.

Means of testing for accuracy.

Precautions to be observed in use.

B. Measurement of illumination intensity with test surface variously inclined and variously located.

C. Measurement of specific intensity of luminous surface. Walls, ceilings, street surface, etc.

D. Illumination tests in a room lighted by various systems.

E. Discussion of results.

Determination of average intensity and illuminating efficiencies.

Sharp and Millar, Elec. World, Jan. 25, 1908.

Sharp and Millar, "Illumination Tests," Trans. Ill. Eng. Soc., 1910, p. 391.

Bechstein, Zeit. f. Instrumentenkunde, Vol. 27, pp. 178-183, 1907.

SPECTROPHOTOMETER

A. Measurement of relative distribution of energy in the spectra of different illuminants.

Instrument, Lummer-Brodhun, Brace or Koenig spectrophotometer.

Study of different methods of altering the illumination of either spectrum; varying slit width, changing distance of source; sector disc.

Koenig, A., Wied. Ann., 53, 785, 1904.

Martens, Ann. de Phys. (4), 12, 984, 1903.

Brace, Phil. Mag. (5), 48, 420, 1899. Astrophys. Jour., 11, p. 6, 1900.

Lummer and Brodhun, Zeit. f. Instrumentenkunde, 12, p. 132, 1892.

COLORIMETER

Instrument, an Ives colorimeter.

A. Measurement of a colored surface as compared with white, in terms of the mixing proportions of three primaries.

B. Measurement of an artificial light source against daylight.

Ives, Herbert E., Trans. Illum. Eng. Soc., 1908. "The Ives Colorimeter in Illuminating Engineering."

Ives, Herbert E., Trans. Illum. Eng. Soc., April, 1910. "Color Measurements of Illuminants."

VISUAL ACUITY APPARATUS

Apparatus used, test object formed by crossed gratings.

A. Determination of the accuracy of visual acuity measurements for measuring illumination. The relationship between illumination and visual acuity.

B. Influence of lights in the field of view on the visual acuity.

Koenig, A., Gesammelte Abhandlungen, p. 378. "Die Abhägigkeit der Sehschärfe von der Beleuchtungsintensität."

Ives, Herbert E., Elec. World, April 14, 1910. "A Visual Acuity Test Object."

MEASUREMENT OF INTRINSIC BRILLIANCIES

Apparatus used, a simple optical pyrometer, in which the background is the image of a Nernst glower, operated at various currents.

INDEX

[Pages 1-524 are in Vol. I; 525-1045, in Vol. II.]

G

H.

I

J

K

L

V

W

Y